WSDA
SPECIALTY CROP BLOCK GRANT PROGRAM
2013
FINAL PERFORMANCE REPORTS

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PART TWO

Project Title: Enhancing Sustainability of Pea Production in Washington

Partner Organization: Washington State University (WSU)

PROJECT SUMMARY

English/garden and edible pod peas are important processing and seed crops in Washington State with a combined production value of approximately $42,000,000 in 2012. Powdery mildew is serious disease threat to pea and is poorly controlled by the use of fungicides. There is no reasonable control option for organic growers. Development and utilization of genetic resistance to powdery mildew are considered an effective and sustainable strategy to manage this disease.

The project was motivated by feedback from growers, processors and breeders of English/garden and edible pod peas. According to a USDA SCRI-funded survey, powdery mildew is identified as the number one disease to pea that reduces crop qualities and results in yield loss up to 50%. Additionally, the spores produced by the fungus can cause allergic reactions and breathing problems for field crews during harvests. Developing powdery mildew resistant peas is essential for English/garden pea and edible pod pea production and is important for the health of field crews. Some edible pod pea varieties, which had previously been classified as resistant to powdery mildew, were observed to be susceptible to this disease in New Zealand and in Columbia and Walla Walla counties in Washington. It was suspected that the pathogen is either overcoming the traditional source of resistance or a new pathogen has been introduced into these regions. The ultimate goals of this project were to understand the pathogen and deploy additional sources of genetic resistance, which result in providing growers and processors with more stable and sustainable high yielding varieties of peas. By addressing the powdery mildew issues, the purposes of this project were to:

- Develop online breeding tools
- Conduct a comprehensive study to screen pea germplasm for additional sources of resistance
- Investigate changes in the genetic identify of the powdery mildew fungus
- Introgress new alleles into elite backgrounds
- Develop extension bulletins and online resources for powdery mildew management in pea.

This project does not build on a previously funded SCBGP project.

PROJECT APPROACH

Goal 1*: develop online breeding tools*

The resistance conferred by the er1 allele has been identified as a loss-of-function of PsMLO and er1 has been successfully cloned and sequenced. Eight breeder-friendly kompetitive allele specific PCR (KASPar) markers, KASPar-er1-1, KASPar-er1-3, KASPar-er1-4, KASPar-er1-5, KASPar-er1-6, KASPar-er1-7, KASPar-er1-8, and KASPar-er1-9, were designed from the PsMLO sequence, based on the mutation information of the er1 alleles. The information on the KASPar markers is available on the cool season food legume website (www.coolseasonfoodlegume.com).

Goal 2*: identify additional germplasm with powdery mildew resistance*

The USDA pea single-plant (PSP) collection was used for a comprehensive evaluation for reaction to powdery mildew. The 246 accessions of the PSP were obtained from the USDA Western Regional Plant Introduction Station, Pullman, WA. The evaluation for reaction to powdery mildew was conducted in two ways, phenotypic evaluation and genotypic evaluation. For the phenotypic evaluation, the collection was planted in a disease nursery at the Oregon State University Horticulture Farm, Corvallis, OR in 2015 and the reaction to powdery mildew was evaluated through visual assessment according to the disease severity key with modifications of methods from the study of Falloon et al. (1995), where 1 = 0-20% of leaflets covered by the disease, 2 = 20-40%, 3 = 40-60%, 4 = 60-80%, 5 = 80-100%. For the genotypic evaluation, DNA was isolated from the leaf tissue using Qiagen DNeasy 96 Plant Kits. Then, the eight breeder-friendly KASPar markers and the corresponding gel-based markers were used to genotype the accessions. Additionally, in collaboration with pathologists and geneticists from John Innes Centre (UK), University of Bari (Italy), Chinese Academy of Agricultural Sciences (China), Universidade do Algarve (Portugal), and Centre for AgriBioscience (Australia), nine resistant, positive controls (JI 1559, JI 210, JI1951, ROI3/02, G0001778, DDR-11, F (er1-8), ps1771 and Yarrum) and one susceptible, negative control (JI 510) were also genotyped.

Goal 3*: Investigate changes in the genetic identify of the powdery mildew fungus*

During the 2014-2015 growing season, 32 powdery mildew isolates were collected from seven regions in U.S.A. and one region in New Zealand. Ten were obtained from greenhouses and the rest were collected from fields. The collected isolates were derived from single pea plants and the collection sites in each region were at least 500 meters apart. Total DNA was extracted from the powdery mildew conidia and mycelia using Qiagen DNeasy Mini Plant Kit. To identify the species of each isolate, internal transcribed spacer (ITS) sequencing assay was used and the amplified fragments were sequenced using an ABI sequencer. Each isolate's species was determined based on the pairwise comparison with the BLAST algorithm in NCBI. To implement population diversity analysis of the collected isolates, thirty simple sequence repeat (SSR) markers were developed from the whole genome sequences of Erysiphe pisi using Msatcommander software. The genotypic data were analyzed by GenAlEx 6.5, Structure 2.3.4, and NTsys 2.1, respectively. GenAlEx was used to analyze number of alleles, allele frequency and Nei's genetic diversity; Structure was used to estimate the possible number of genetic population using Bayesian method; NTsys was used to perform principal component analysis (PCA).

Goal 4*: introgress new alleles into elite backgrounds*
A third, dominant allele, Er3, for powdery mildew resistance was identified in one of pea's wild relatives – Pisum fulvum. This allele confers immunity to pea. Three germplasm lines containing Er3 were obtained from the Institute for Sustainable Agriculture, CSIC, Córdoba, Spain. Pisum fulvum has very small, darkly pigmented seeds. The plants are very tall, with very thin stems, small leaflets and pigmented flowers. A series of crosses was initiated using the P. fulvum accessions as male and garden peas as the female. These interspecific crosses were difficult to make and in the ensuing F1 and F2 generations, there was considerable male sterility. Two back crosses were made (eg. P. sativum x F1) to obtain BC2F2. Ten single plant derived progenies from this generation were evaluated for resistance to powdery mildew in 2016 in the field nursery at Oregon State University. Single plants that were resistant to powdery mildew were harvested. Because Er3 is dominant, it is necessary to progeny test the resistant lines to determine if they are heterozygous or homozygous. These lines are currently being grown for seed increase for progeny testing and the homozygous resistant lines will be released as germplasm in 2017.

Goal 5*: develop extension bulletins and online resources for powdery mildew management in pea*
This goal/objective was discontinued as the objective was met through the development of disease diagnostic cards by the pulse working group (of which all PI's on this project are members). Resources allocated for this goal were not spent and were returned.

The significant contributions and roles of project partners are as follows:

- *Rebecca McGee, PI*. Dr. Rebecca McGee oversaw, directed and guided this project, reviewed the project timeline and activities, and prepared quarter, annual and final reports to WSDA. Additionally, she was in charge of introgressing er2 and Er3 alleles into elite backgrounds and evaluated the PSP collection for reaction to powdery mildew in the field.
- *Clare Coyne, Co-PI*. Dr. Clare Coyne oversaw the genotyping aspects of this project and the development of the KASPar markers. She provided the PSP collection for identification of additional germplasm with powdery mildew resistance.
- *Dorrie Main, Co-PI*. Dr. Dorrie Main oversaw the bioinformatics portions of this project. She was responsible for developing the Cool Season Food Legume website.
- *Carol Miles, Co-PI.* Dr. Miles was responsible for Goal 5, which was discontinued.
- *Jodi Humann.* Dr. Jodi Humann was the Laboratory Project Manager, who ensured that expenditures remain within the budget categories and the funds were spent appropriately.
- *Yu Ma.* Ms Yu Ma conducted the majority of the laboratory experiments during this project as part of the research requirements for a Ph.D. degree. She was responsible for development and validation of KASPar markers, identification of additional resistant germplasm using DNA markers, investigation of the genetic diversity of collected powdery mildew isolates and data analysis. She assisted in the preparation of the final report to WSDA.

This project did not benefit any non-specialty crops.

GOALS AND OUTCOMES ACHIEVED

The activities to achieve the expected outcomes are included in the descriptions above. The performance goals of this project were closely met.

***Goal 1**: increase production potential for English/garden and edible pod peas*

This became a long term goal due to the unexpected difficulties encountered with male sterility in the interspecific crosses. Germplasm known to be homozygous for Er3, and therefore immune to powdery mildew will be released in 2017. The long term goal of introgressing multiple powdery resistant alleles into elite backgrounds is still in progress – the Er3 germplasm will continue to be improved for agronomic traits while retaining Er3. er1 will be combined with Er3 using the KASPar markers. Tools for breeders to use in improving the powdery mildew resistance in their breeding programs include the KASPar markers developed for er1 – er8. In approximately 3 years, introgression of er1 and Er3 into elite backgrounds will be complete and the increased production potential of the new cultivars carrying both genes for powdery mildew resistance can be measured.

***Goal 2**: develop online breeding tools*

The eight low-cost, breeder-friendly KASPar markers were developed from the mutation information of the er1 alleles to assist in pyramiding multiple and specific powdery mildew resistant alleles. The manuscript is currently in preparation and expected to be submitted to Molecular Breeding journal in December 2016. The KASPar markers will be freely available and disseminated immediately following publication of the results. The relevant information will be included on the CSFL website.

***Goal 3**: identify additional germplasm and varieties with powdery mildew resistance*

For the phenotypic evaluation of the PSP collection for reaction to powdery mildew, the results showed seventeen pea accessions were found to be highly resistant to powdery mildew with a disease score of 1. These lines included W6 17293, W6 39729, W6 39761, PI 102888, PI 116944, PI 142775, PI 179451, PI 183467, PI 207508, PI 220174, PI 220189, PI 222071, PI 222117, PI 273605, PI 274307, PI 307666, and PI 486131. Among these, 16 were P. sativum and one was P. sativum var. arvense (W6 17293).

For the genotypic evaluation, the results showed the KASPar markers developed in this study worked perfectly to detect powdery mildew resistance except KASPar-er1-9. The results can be easily visualized through Bio-Rad CFX Manger software. Figure 1 is an example of KASPar-er1-1 on 18 pea accessions from the PSP collection. Individuals clustered in the upper left (purple) are homozygous for HEX-labeled er1/er1 powdery mildew resistance. Individuals clustered in lower right (orange) are homozygous for FAM-labeled Er1/Er1 powdery mildew susceptibility. Individuals clustered in the lower right (black) are no template controls and samples failed to identify because of evaporation during PCR amplifications. To validate the genotypic results using the eight KASPar markers, the pea accessions were also genotyped using the corresponding functional markers. From the genotypic evaluation of the PSP collection, one accession, PI 142775, was found to carry the er1-1 allele and was resistant to powdery mildew. However, no accessions were found to carry the other er1 alleles, er1-3, er1-4, er1-5, er1-6, er1-7, and er1-8. Given the 2-bp insertion for er1-9 allele occurs in an intron of the PsMLO gene, it is difficult to conclude whether KASPar-er1-9 works perfectly.

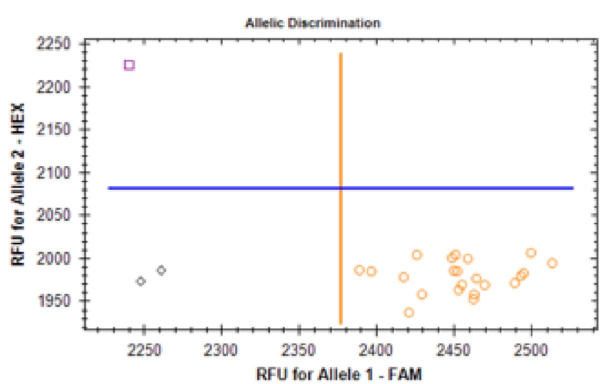

Figure 1. Result of genotyping with the marker KASPar-*er1-1* on 18 pea accessions

***Goal 3**.1: Investigate changes in the genetic identify of the powdery mildew fungus*

According to the ITS sequencing results, two isolates collected from a greenhouse in Washington State were found to be E. trifolii, while the rest of the isolates were E. pisi and none of collected isolates belonged to E. baeumleri (Figure 2). E. pisi is likely to be the main powdery mildew species in North America. However, it is still unknown if E. pisi is dominant in New Zealand due to limited numbers of samples (2 samples). More samples should be collected in this region in future study.

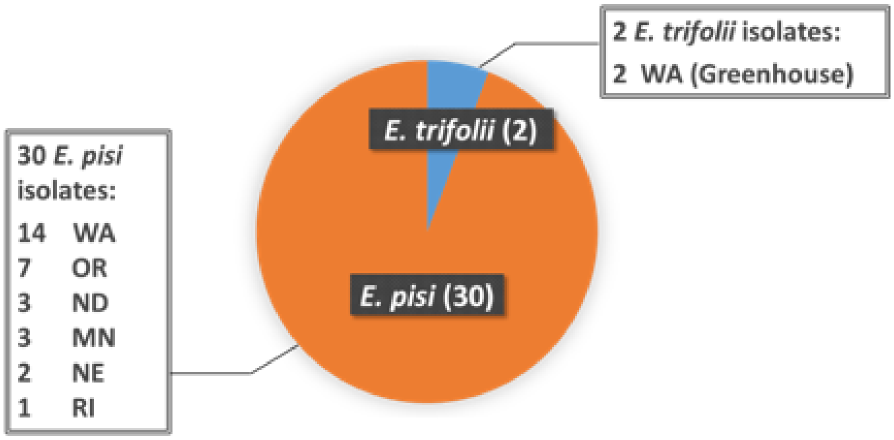

Figure 2. Pie chart of percentage of powdery mildew species from selected regions

The collection of powdery mildew isolates studied in this project was highly polymorphic, which was indicated by Nei's genetic diversity with values ranging from 0.1 to 0.6. The number of alleles per locus for SSR markers ranged from 2 to 7. Interestingly, two SSR markers can distinguish E. pisi from E. trifolii. The population structure of collected isolates was examined by PCA. Four distinct clusters differentiated by PC1, PC2 and PC3 were observed in Figure 3. E. trifolii was separated from E. pisi, while isolates from OR and ND were distinguished from the rest of regions. In agricultural ecosystems, environmental changes such as resistant varieties, applications of fungicides, irrigation, and crop rotation may cause population structure different from place to place. In OR, the sample-collected areas are disease nurseries where diverse pea varieties are planted. In ND, the sample-collected area has a humid climate with warm summers and no dry season. These factors may be the reason causing powdery mildew isolates in these areas different from others.

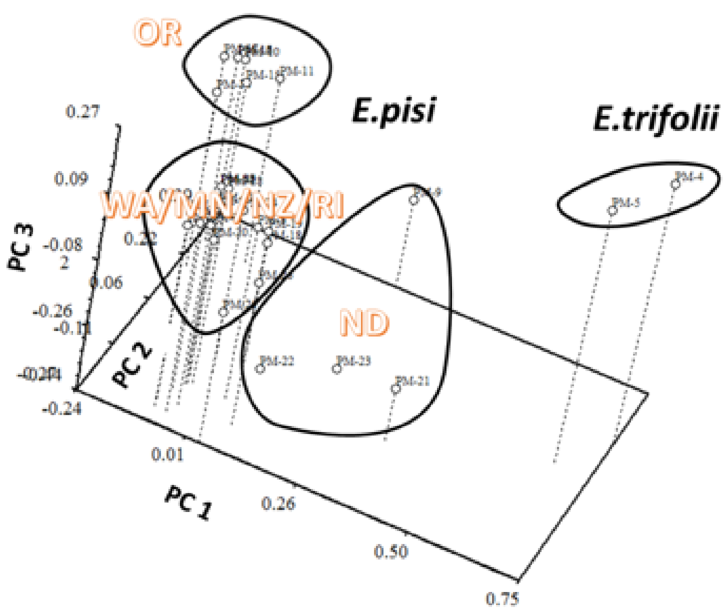

Figure 3. Principal component analysis of population structure among thirty-two powdery mildew isolates

Goal 3.2: *introgress new alleles into elite backgrounds.*

This goal has become a long term goal. There was an unexpected high level of male sterility associated with the interspecific crosses. This resulted in having to make much larger populations than initially anticipated in order to have a sufficient population to phenotype in the field. As a result, instead of being able to release finished varieties, only germplasm with Er3 introgressed will be released into adapted backgrounds. This part of the project will continue to be worked on. It is anticipated that within 3 years cultivars will be released with durable resistance to powdery mildew conferred by Er3 and er1.

Goal 4*: develop extension bulletins and online resources for powdery mildew management in pea.*
This goal was discontinued due to an extremely similar project completed by the Pulse Crop Working group. The project was to develop durable pocket reference cards for identification of common pea diseases.

Established activities and goals	**Actual accomplishments**
Goal 1: *Increase the production potential for English/garden and edible pod peas*	This goal was only partially met. The final development and deployment of pea cultivars with pyramided resistance (*er1* and *Er3*) to powdery mildew was not met because of the difficulties encountered in making the interspecific crosses between *P. sativum* and *P. fulvum* (source of *Er3*). The amount of male sterility encountered was not expected. Currently, elite lines have been identified that carry Er3, however until progeny testing is completed, it is not known if the lines are homozygous (*Er3Er3*) or heterogyzous (*Er3er3*). Following identification of the homozygous lines, seed will be increased and evaluated for increased production potential.
Goal 2*: develop online breeding tools* • Development and introduction of a breeders' toolbox on the Cool Season Food Legume. Upload phenotype and genotype data into breeders' toolbox and make data and cross-assistance tool publicly available • Development of low-cost, breeder-friendly markers.	Activities completed. Goal met. • KASPar markers have been uploaded into CSFL and will be made public immediately following publication of manuscript. • The eight low-cost, breeder-friendly KASPar markers were developed from the mutation information of the *er1* alleles to assist in pyramiding multiple and specific powdery mildew resistant alleles.
Goal 3 *develop new germplasm and varieties with improved levels of durable resistance to powdery mildew* • Identify resistant pea germplasm form the USDA collection by screening in controlled and field (irrigated) conditions	Activities completed. Goal met. • The 246 pea accessions from the USDA collection were evaluated for reaction to powdery mildew in the disease nursery in OR (2015). Seventeen pea accessions were found to be highly resistant to powdery mildew • The same pea accessions were evaluated using the KASPar markers developed in Goal 1 and the corresponding gel-based markers. One accession, PI 142775, was found to carry the *er1-1* allele and was resistant to powdery mildew.
• Determine pathogen species & pathotypes. In addition to cooperator provide samples, systematic sampling in WA. • Learn the nature of the diversity of the pathogen	• Thirty-two powdery mildew isolates were collected from seven regions in U.S.A. and one region in New Zealand during the 2014-2015 growing seasons. Two isolates collected from a greenhouse in Washington State were found to be *E. trifolii*, while the rest of the isolates were *E. pisi*. The collection of powdery mildew isolates studied in this project was highly polymorphic

	and population structure of the pathogen was discovered.
• Introgress Er3 from *Pisum fulvum* and er2 into elite sugar snap, snow and English pea backgrounds	• Er3 has been introgressed (initial cross and 2 back crosses) into adapted English pea backgrounds. Work is continuing on stacking the *er1* and *Er3* alleles. The resistance conferred by *er2* is weak and became a low priority.
***Goal 4**: develop extension bulletins and online resources for powdery mildew management in pea* • Target: Two extension publications and on-line diagnostic decision tree	This goal was discontinued due to extremely similar work performed by the Pulse Working Group.

The first Expected Measurable Outcome was ***to increase the production potential for English/garden and edible pod peas***. During this project much effort was spent transferring the powdery mildew resistance conferred by Er3 from Pisum fulvum to Pisum sativum. The original intent was to transfer Er3 through a series of fast backcrosses, however the problems encountered with male sterility associated with the interspecific crosses really slowed this process down. Additionally, not having a biomarker for Er3 made progeny testing a necessity in order to identify lines that were homozygous dominant for Er3. In hindsight, a request to change or amend this EMO should have been requested. Although it was anticipated that EMO 1 would be met, as the project progressed that wasn't possible. A considerable amount of outreach was performed. During the three years of this project, information on the powdery mildew and the progress of this project was presented at one disease diagnostic clinic (50 participants); 15 field days at variety trials (total 345 participants); 4 field days at WSU Research Farms (705 total participants); 5 Grower Meetings (370 total participants). A considerable amount of knowledge was also gained regarding the population genetics of powdery mildew in Washington. In Washington there are two species of Erysiphe that cause powdery mildew on peas – E. pisi and E. trifoli. It was determined that E. pisi is the most common species in fields. Population genetics studies revealed that there are four distinct clusters of genotypes. Further research will determine if the four clusters have similar of different responses to the different er/Er genes and alleles.

The second outcome of this project was ***the development of online tools for breeders***. This includes the development and introduction of a breeder's toolbox on the Cool Season Food Legume website (www.coolseasonfoodlegume.org). KASPar markers have been developed and validated for the er1 alleles. Immediately following publication of the manuscript, these tools will be freely available on the CSFL website for all breeders to use.

The third outcome was the development ***of new germplasm and varieties with improved levels of durable resistance to powdery mildew***. Much was learned about the nature of the population genetics of powdery mildew in naturally infested fields in the state of Washington. Selected lines are currently being progeny tested to select lines that are homozygous dominant for Er3 seed will be increased in the summer of 2017 and germplasm will be released that carries immunity to powdery mildew conferred by Er3. Work in on-going to pyramid the resistance conferred by er1 and Er3 and cultivars and/or germplasm will be released in about 2019 that have extremely durable resistance due to the pyramiding of resistance alleles at both er1 and Er3.

BENEFICIARIES

Direct beneficiaries include pea breeders who now have a breeder friendly marker to use to help select for powdery mildew resistance in very early stages of their breeding programs. They also have access to a third source of resistance to powdery mildew, Er3. Er3 was successfully transferred from the wild relative, Pisum fulvum, into P. sativum and issues with male sterility were successfully overcome. Beneficiaries of future pea cultivars with the durable combination of er1 and Er3 or Er3 alone will include all growers and processors of garden and edible pod peas.

This project primarily impacts Washington growers and processors of peas. The growers and processors were impacted immediately by understanding the identity of the pathogen and learning the nature of the diversity. They will directly benefit from the resistant varieties developed in this research which increased yields and reduced costs of production (by eliminating use of fungicides). Also, they will benefit over time by accessing online tools that would assist them to efficiently manage varieties with durable resistance.

English/garden and edible pod peas had a combined production value of approximately $42,000,000 in 2012. The primary economic impact of this project is preventing yield losses and the secondary impact is reduced fungicide use. These economic impacts will be realized with the further development of pea cultivars carrying er1 and Er3 or Er3 alone.

LESSONS LEARNED

Interspecific crossing was unexpectedly difficult and the amount of male sterility encountered made it very hard to make the breeding progress initially anticipated.

It was not expected that only one accession from the PSP would have a known er1 allele. This leads to the hypothesis that there either are more than the nine previously published er1 alleles present in the PSP or that there are new, unidentified er alleles present. The hypothesis could be tested by making a series of crossing between the lines known to carry an er1 allele and the unknowns followed by progeny testing.

The number of powdery mildew isolates collected in the selected regions is much less than expected. Twenty pathologists/pea breeders were willing to help collect powdery mildew isolates in their regions. However, powdery mildew symptoms did not appear in most of their regions last year, which resulted in a small sample size with thirty-two isolates for genetic diversity analysis. The pathogen is prevalent in areas with a warm, humid climate, while the climate throughout US last year was relatively dry and powdery mildew symptoms were hardly observed under dry weather conditions with high temperature.

Another unexpected difficulty was the purification of collected isolates. The powdery mildew fungus is obligate, biotrophic pathogen, which indicates it can only grow in living hosts for growth and reproduction. It is more difficult to culture biotrophic fungus than necrotrophic fungus. The environmental condition of greenhouses is very important for the successful inoculation, such as temperature, humid, fungicide-free. However, the attempt of isolate purification failed because the application of sulfur fungicides was not noticed during the inoculation.

The goal of creating extension publications was not met –due to extremely similar work performed by the Pulse Working Group.

ADDITIONAL INFORMATION

Item	Year (s)	Value/year	Total Value
Laboratory Bench Space and misc. supplies (McGee)	2014, 2015, 2016	$500	$1500
Laboratory Bench Space and misc. supplies (Coyne)	2014, 2015, 2016	$500	$1500
Growth Chambers (2)	2014, 2015	$1440	$2880
Greenhouse supplies (McGee)	2014, 2016	$500	$1000
Greenhouse supplies (Coyne	2014, 2016	$500	$1000
Field Screening Nurseries (including labor, travel and land)	2014, 2015	$2000	$4000
Tuition Waiver (Yu Ma)	2014-2015	Approx. $15,400	
TOTAL			$27,280

Presentations related to this project were made at about 8 field days and 4 grower meetings per year.

Publications:

This project resulted in Chapter 4 of Yu Ma's Ph.D. thesis, "Enabling Marker-Assisted Breeding in Pea", 2016. Department of Horticulture, Washington State University, Pullman, WA.

Yu Ma, Clare J. Coyne, Dorrie Main, Stefano Pavan, Shimna Sudheesh, Sukhjiwan Kaur, John W. Foster, José Leitão, Suli Sun, Zhendong Zhu, Xuxiao Zong, and Rebecca J. McGee. Development and validation of breeder-friendly KASPar markers for er1, a powdery mildew resistance gene in pea (Pisum sativum L.). Molecular Breeding. (In preparation)

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Project Title: Effectiveness of ET-, Soil-, and Plant-Based Tools for Irrigation Strategies

Partner Organization: Washington State University (WSU)

PROJECT SUMMARY

The initial purpose of this project was to provide a scientific basis of and practical recommendations for enhanced irrigation management in support of the rapidly expanding wine industry in Washington State. The Washington wine industry is embarking on its next major expansion phase, yet many wine critics complain that the overall quality of white wines from this state lags behind red wine quality. Two varieties, Chardonnay and Riesling, account for 75% of all white wine made in Washington, yet virtually no research has been conducted to determine optimum irrigation strategies for these varieties.

Knowledge of irrigation management for white wine grapes is insufficient. Such research is important and timely, not only because these varieties continue to be a major component of the continued industry expansion, but also because most of these grapes are grown in arid eastern Washington, where highly efficient drip irrigation is the principal management tool to impact yield, quality, and sustainability of premium grape production. To address this issue, this study had three objectives:

- Evaluate the effectiveness of different decision-aid tools (ET-, soil-, and plant-based approaches) for irrigation scheduling, and determine the best approach for directing irrigation of white wine grapes;
- Investigate the influence of different irrigation regimes on white wine grape growth, physiology, yield, fruit composition, and wine quality, and optimize irrigation strategies for high-quality white wine grape production;
- Enhance practical recommendations for irrigation management of white wine grape varieties.

This project is not built on a previously funded SCBGP project.

PROJECT APPROACH

Activities and accomplishments during the entire duration of this project (September 2013 – September 2016) are presented in chronological order as follows (when possible, repeated activities across years were combined):

- A Postdoctoral Research Associate was hired and began work on the project on October 1, 2013.
- The Work Plan indicates that project activities were to begin in January, 2014. However, using matching funds from the Washington State Wine Commission and in-kind contributions from the industry cooperator, the irrigation systems of two commercial vineyard blocks were modified and the proposed field trials established during the 2013 growing season. Soil samples were taken from both vineyards for soil moisture retention curve analysis to obtain accurate values of field capacity and permanent wilting point (beyond Work Plan).
- The Work Plan specifies six irrigation treatments (named T0 through T5; Table 1). One additional treatment (T6: partial rootzone drying, PRD) was added onto this project (beyond Work Plan). Consequently, seven irrigation treatments (Table 1) were implemented in two vineyard blocks (Chardonnay and Riesling).
- Data were collected during each of three growing seasons (April-September, 2014, 2015, and 2016). Data collection included weekly measurements of soil water status (volumetric soil water content, θv) and plant water status (midday stem water potential, Ψs), plant physiological and growth responses (leaf gas exchange, stomatal conductance, shoot growth, canopy density, fruit light exposure), and yield components and fruit composition (total soluble solids, pH, and titratable acidity). Wines from selected irrigation treatments harvested in each year were made by the cooperator at the WSU Wine Science Center in Richland (September-March). Pruning weights were measured and canes counted in February 2015 and 2016.
- Benchmark industry data for the beginning and the end of this project were compiled to evaluate the proposed target and to estimate measurable outcomes. Data were collected in cooperation with the Washington State Wine Commission and the Washington Association of Wine Grape Growers, in addition to data published by USDA-NASS.
- The PI hosted a visiting MS student from Geisenheim University, Germany, from May through November 2014, and a PhD student from the University of Milano, Italy, from July 2014 through February 2016. The students worked with the Postdoctoral Research Associate to study effects of irrigation treatments and fruit exposure on vine

physiological responses and on chemical components responsible for bitterness and astringency in white grapes (beyond Work Plan).

Significant results and conclusions (for tables see the “Additional Information” section below):

- A description of the seven irrigation treatments is provided in Table 1. Treatments T0, T1, and T2 were implemented to test three different approaches to irrigation scheduling. The weekly amount of irrigation water to be applied in T0 (ET-based approach) was based on replacing 100% of crop evapotranspiration. The goal for T1 (soil-based approach) was to maintain soil water content (□v) near or above non-stress levels (□v ≥ 16% v/v). The goal for T2 (plant-based approach) was to maintain stem water potential (Ψs) near or above non-stress levels (Ψs ≥ -0.7 MPa). Treatments T3 through T6 were designed to test method and timing of deficit irrigation. For T3, T4, and T5 the target for moderate stress was 12% < □v < 16%, and -1 MPa < Ψs < -0.7 MPa. For PRD (T6), the drying side was irrigated when its □v ≤ 12% to increase □v to ≥16%.
- Comparison of three different irrigation decision-aid tools (T0, T1, and T2):
    - Chardonnay: As planned, little difference was found in □v and Ψs among T0, T1, and T2 (Table 2). There was no difference in leaf gas exchange in all three years. Canopy growth and density of T0, T1, and T2 had different results among the three years (Table 4). In 2014, T0 vines generally had larger and denser canopies (more leaf layers, less light interception in the fruit zone, and more lateral leaves per shoot), compared with T1 and T2. Yet, no differences were found in 2015. Similarly in 2016, most measures of canopy growth and density showed no difference among these three treatments, except that T2 had more leaf layers than T0 and T1 at harvest. Minor differences in yield components were found among these treatments (Table 6). In 2014, T0 had higher yield than T2, and the highest berry weight of all three. In 2015 and 2016, T1 had higher yield than T0 and T2; T0 had lower cluster number than T1. In 2016, T0 also had lower cluster weight and fewer berries per cluster than T1. The inconsistencies in these results may be explained by the variation in irrigation amounts across the three years: in 2014, T0 received the highest amount of irrigation water, while it had the least irrigation in 2015 and 2016 (Table 8). In terms of fruit composition at harvest, little difference was found in all three years (Table 6).
    - Riesling: In general, T0 had higher □v and Ψs than T1 and T2, but there was no difference between T1 and T2 (Table 3). Little difference in leaf gas exchange was found among these treatments. Vines of T0 had larger and denser canopies (more leaf layers, less light interception in the fruit zone, and higher shoot vigor) than T1 and T2 across the three years (Table 5). Few differences were found between T1 and T2. In terms of yield components (Table 7), T0 had the highest yield in all three years, higher berry weight in 2014 and 2015, and higher cluster weight in 2015 and 2016. More irrigation in T0 may explain the higher vigor and productivity of these vines (Table 8). The relatively small differences in irrigation amounts between T1 and T2 (Table 8) were apparently insufficient to result in yield differences between these two treatments. Little difference was found in fruit composition in all three years (Table 7).
    - Among these three irrigation decision-aid tools, all the data inputs for irrigation decision-making of T0 (replacing 100% of crop evapotranspiration, ETc) were acquired from a nearby AgWeatherNet weather station. Therefore, this tool required no additional, vineyard-based measurements. However, the accuracy of ETc relies on the accuracy of reference evapotranspiration (ET0) and crop coefficient (Kc). If the local conditions of the weather station are rather different from those of the vineyard block, or if the estimate of Kc does not reflect the actual situation of the vineyard, unexpected results may occur when irrigation decisions are made solely based on ETc. For example, higher □v and Ψs in T0 than T1 and T2 (Table 3) indicated that ETc was overestimated for the Riesling block. This led to a 71% greater irrigation water supply in T0 compared with the other decision-aid tools (Table 8). Scheduling irrigation based on □v (T1) or Ψs (T2) measured in the vineyard avoided this problem by providing data inputs for decision-making reflecting the local conditions. However, either approach required extra inputs of equipment and labor. This is especially true for T2, because Ψs only indicated whether or not irrigation was needed, an additional parameter (in this study □v) was needed to determine the amount of irrigation. Also, Ψs can be influenced by weather conditions, in particular temperature and humidity.
- Comparison of four deficit irrigation regimes (T3, T4, T5, and T6):
    - Chardonnay: Compared with the no-water-stress treatments (T0, T1, and T2), the deficit irrigation treatments in general had lower □v and Ψs, which led to less vigorous shoot growth, more open canopies,

lower yield, lower berry and cluster weights, and lower titratable acidity (Tables 2 and 4). From veraison to harvest in all three years, T4 and T5 had higher □v and Ψs than T3, which indicates that water stress was relieved as planned (Table 2). However, leaf gas exchange in T4 and T5 was only higher than T3 in 2015. In 2014, T6 had more leaf layers than the other three deficit treatments, and more vigor and less light interception in the fruit zone than T5. In 2015, T3 had fewer leaf layers and T6 had higher vigor than the other deficit treatments; T6 also had less light interception than T3 and T4. In 2016, T6 had more canopy growth and denser canopies than T3; T4 and T5 were either intermediate between, or no different from, T3 and T6. In terms of yield components (Table 4), T6 generally had higher yield and often the highest berry weight among the deficit treatments, even though the amount of irrigation water supplied in T6 was similar to the others deficit treatments (Table 8). Little difference was found in fruit composition among these deficit treatments in 2014 and 2015, but in 2016 grapes from T6 had higher acidity than those from T3 and T5 (Table 6). Importantly, berry skin phenolics (flavonols and monomeric, oligomeric, and polymeric flavan-3-ols) were not impacted by the irrigation regime per se, but sun exposure led to an eight-fold increase in flavonols, and a fourfold increase in flavan-3-ols compared with shaded berries (data not shown). This suggests that any potential irrigation effect on bitter or astringent wine phenolics likely occurs via its effect on canopy structure, and thus on light exposure of the fruit.

- Riesling: In general, the deficit irrigation treatments resulted in lower □v and Ψs, and thus led to lower shoot vigor, more open canopies, lower yield, and lower berry and cluster weights than in T0, and lower titratable acidity in 2014 and 2016 (Tables 3, 5, and 7). However, growth and yield components in these deficit treatments differed only occasionally from T1 or T2, despite lower irrigation water supply in the deficit treatments (Table 8). Among the deficit treatments, no consistent differences in canopy growth and density were found across the three years, except that T3 vines tended to have fewer leaf layers. From veraison to harvest in both 2015 and 2016, T4 and T5 had higher □v, Ψs, and leaf gas exchange than T3, which indicates that water stress was relieved as planned (Table 3). In terms of yield components and fruit composition, few or inconsistent differences were found, except that T6 often had higher berry weights than the other deficit treatments (Table 7), with similar amounts of irrigation water (Table 8). The results for fruit phenolic compounds were similar to those found in Chardonnay, with sun exposure resulting in a six-fold increase in flavonols, and a two- to three-fold increase in flavan-3-ols. Overall, Riesling produced much lower amounts of flavan-3-ols than Chardonnay, while flavonol levels were similar (data not shown).

Recommendations:

- It is feasible to schedule irrigation based on either ETc, □v, or Ψs. Each approach has its pros and cons, resulting in trade-offs between accuracy and labor/equipment demands, as described above. In order to improve the applicability of the ET-based approach, the current model for estimating Kc based on growing degree days may require adjustments to suit the local conditions of the vineyard. An alternative solution would be to adopt a different method that can estimate Kc locally. If using the ET-based approach, it would be advisable to at least employ either soil- or plant-based measurements to check whether intended irrigation goals are achieved under local conditions.
- Excessive water deficit should be avoided in white wine grape production. Overall, the T3 treatment that imposed moderate water stress throughout the growing season tended to produce the smallest canopies that were associated with high sun exposure of the fruit. Although water stress does not appear to directly impact grape phenolics that impart bitterness or astringency in wine, an increase in fruit exposure due to water deficit will nevertheless have a detrimental impact on these quality-relevant components. It should be noted that only moderate water stress was applied in the present experiments. More severe stress, which is known to result in leaf abscission in the fruit zone and in sunburn symptoms on the fruit, presumably would worsen the situation for wine phenolics.
- With similar or occasionally more canopy growth and little difference in fruit composition compared with conventional deficit irrigation regimes (T3, T4, and T5), partial rootzone drying (T6) may be beneficial considering its higher yielding with similar irrigation water usage. Also, the irrigation decision was easy to make based on □v of two separate rootzones: irrigation was initiated on the drying side and stopped on the wet side whenever □v of the drying side fell below 12% (v/v). This threshold could be adapted to different soil types for integration in automated irrigation decision-support tools.

Significant contributions and roles of project partners include:

- The PI (Dr. Markus Keller) provided overall project management, direction, and oversight and supervised the Postdoctoral Research Associate (Co-PI, Dr. Yun Zhang), a visiting PhD student (from University of Milan, Italy), a visiting MS student (from Geisenheim University, Germany), two technicians, and four student interns who assisted with trial establishment and data collection. The PI also collected benchmark data from industry stakeholder groups, submitted the progress reports to WSDA, and ensured that expenditures remained within budget categories and that funds were spent appropriately. In addition, the PI gave annual written and oral reports to the industry advisory committee and several oral presentations on irrigation management to industry stakeholders, as well as to the scientific community.
- The Postdoctoral Research Associate (Co-PI, Dr. Yun Zhang) co-supervised a visiting PhD student, a visiting MS student, and four student interns, and carried out most of the day-to-day activities and measurements in the experimental vineyards, and conducted the data analysis. Also, this Co-PI gave several oral presentations and poster presentations on irrigation management to industry stakeholders and to the scientific community, participated in a discussion panel at an industry meeting, coordinated work with all cooperators, and facilitated report preparation.
- The other Co-PI (Dr. Troy Peters) contributed to the design and modification of irrigation systems and the set-up of the field trials. Also this Co-PI facilitated the progress of this project through discussions, and gave several presentations on irrigation system design and management to industry stakeholders.
- The industry cooperator (Dr. Russell Smithyman) oversaw the collaborating company's in-kind commitment, ensured that standard viticultural practices were implemented at the field trial sites, and donated the fruit for harvest analysis and winemaking.
- The other cooperator (Dr. James Harbertson) supervised winemaking from the fruit harvested from the selected treatments.

This project does not benefit non-specialty crops.

GOALS AND OUTCOMES ACHIEVED

The main goal of this project was to provide basic information to ultimately develop practical recommendations for irrigation decision-aid tools and irrigation strategy to enhance white wine grape production. Measurable outcomes include: expand acreage for white wine grapes; increase average crop yields of white wine grapes; and improve overall quality of white wine grapes, which will result in an increase in the price paid for grapes. To achieve these goals, outputs generated through this project have been shared with the state's more than 350 wine grape growers through various outlets. These completed activities include:

- In cooperation with the Washington State Wine Commission and the Washington Association of Wine Grape Growers, in addition to using published USDA-NASS data, benchmark data were compiled for 2013: total white wine grape tonnage (103,200 tons); average price of white wine grapes ($852/ton); total acreage of white wine grapes planted (18,851 acres; acreage data were available for 2011).
- The PI presented written and oral project progress reports to the industry advisory committee in Richland, WA (January/February 2014, 2015, 2016).
- The PI and the Postdoctoral Research Associate met several times with the industry cooperator in Prosser, WA, to discuss project progress and requirements, responsibilities, and activities for each growing and harvest season.
- The PI and Co-PIs gave a total of seven invited presentations about wine grape irrigation management at the Annual Meeting of the Washington Association of Wine Grape Growers in Kennewick, WA (February 2014, 2015, 2016).
- The PI gave two invited presentations on wine grape irrigation at the 10th Annual Sustainable Ag Expo in San Luis Obispo, CA (November 2014; beyond Work Plan).
- The Postdoctoral Research Associate presented on a discussion panel on "Early watering in wine grape production" at the Washington State Grape Society Meeting (Grandview, WA) in November 2014 (beyond Work Plan), and presented a poster of preliminary results from this project at the same meeting in November 2015.
- The Postdoctoral Research Associate gave a presentation on irrigation methods in wine grapes at the Grape Fieldmen's Breakfast in Prosser, WA (December 2014).
- The Co-PI gave an invited presentation at the Small Fruits Conference on irrigation management for small fruits in Lynden, WA (December 2014).

- The Co-PI presented a poster on irrigation water management at the Washington State Horticultural Convention in Kennewick, WA (December 2014).
- The PI gave an invited guest lecture on vineyard deficit irrigation at Cornell University, Ithaca, NY (April 2015; beyond Work Plan).
- The Postdoctoral Research Associate gave a poster presentation about this project at the 19th International GiESCO Symposium in Gruissan, France (June 2015; beyond Work Plan).
- The PI and the Postdoctoral Research Associate gave a total of three oral presentations on vineyard irrigation management and current results from this project at the American Society for Enology and Viticulture National Conference (June 2015, 2016).
- The PI and the Postdoctoral Research Associate led tours of the National Grape and Wine Initiative Board of Directors and a group of Argentinian viticulturists and winemakers to one of the trial blocks to showcase this project (July and August 2015; beyond Work Plan).
- The PI gave an invited presentation about fruit ripening and vineyard irrigation at the Southeastern United Grape and Wine Symposium in Dobson, NC (November 2015; beyond Work Plan).
- The PI gave an invited oral presentation about grape ripening and irrigation effects at the Oregon Wine Symposium in Portland, OR (February 2016; beyond Work Plan).
- The PI gave an invited oral presentation about vineyard irrigation at the annual technical retreat of Constellation Brands in Fish Camp, CA (May 2016; beyond Work Plan).
- The Postdoctoral Research Associate gave an oral presentation about grape berry water relations and ripening at the X International Symposium on Grapevine Physiology and Biotechnology in Verona, Italy (June 2016).
- The PI gave an invited oral presentation about WSU irrigation research at the 1st WAVE (Washington Advancements in Viticulture and Enology) event sponsored by the Washington State Wine Commission in Richland, WA (July 2016; beyond Work Plan).
- The PI was interviewed about this project by the following media: New York Times (May 2015), Cherry Creek Radio (January 2016), Western Fruit Grower (April 2016), Great Northwest Wine News (April 2016; beyond Work Plan)

Because changes in irrigation management require time for adoption by growers, the final targets of Expected Measurable Outcomes will be evaluated two years after the end of this project (September 2018). Therefore, besides all the completed activities listed above, future activities that will be performed beyond the Work Plan to achieve these targets include:

- The Postdoctoral Research Associate will present a poster of current results from this project at the annual meetings of the Washington Grape Society in Grandview, WA (November 2016) and the Washington Association of Wine Grape Growers in Kennewick, WA (February 2017).
- The PI will give an invited seminar and invited keynote presentation about grape ripening and irrigation at the University of Bordeaux, France, and the InnoVine Meeting in Toulouse, France (November 2016).
- The PI, Co-PI, and Postdoctoral Research Associate will give presentations of final project results at future meetings of the Washington Grape Society in Grandview, WA (November 2018) and the Washington Association of Wine Grape Growers in Kennewick, WA (February 2019).
- Novel scientific knowledge generated through this project will be published in appropriate peer-reviewed journals. Where applicable, such knowledge will also be integrated into online tools that are available to the public (e.g. irrigation.wsu.edu, weather.wsu.edu).
- Wines from selected irrigation treatments that have been and are being made by the cooperator will be evaluated; knowledge on the impact of irrigation regimes on wine quality will be disseminated to the industry.

Almost all of the activities proposed in the Work Plan have been completed. The two field experiments were completed by the end of the grant agreement. However, because grape harvest occurred in September 2016, wine making, data compilation, and data analysis will continue beyond the end of the grant period. Therefore, conclusions and recommendations will be finalized after the end of this grant, including integration of the best irrigation strategies into online irrigation decision-aid tools. This additional work will be funded by the Washington State Wine Commission. The only activity in the Work Plan that was not accomplished was the proposed demonstration of the field trial sites during the WSU Viticulture and Enology field day in August 2016, because the organizers decided to focus field day activities in a different grape growing region. To compensate, project results and recommendations have been, and will continue to be, widely disseminated through presentations at the annual meetings of the Washington Association of Wine Grape Growers and the Washington State Grape Society, and through other avenues as described above.

Baseline data were gathered in cooperation with the Washington State Wine Commission and the Washington Association of Wine Grape Growers, and using publicly available data released by USDA-NASS. The initial baseline data for the three Expected Measurable Outcomes in the proposal were:

- White wine grape acreage in 2011: 18,851 acres (total wine grape acreage: 43,849 acres)
- Total white wine grape production in 2011: 78,300 tons (average crop yield: 4.15 tons/acre)
- Average price for white wine grapes in 2012: $844/ton

The measurable outcome targets for this project were to increase (1) acreage by more than 25%; (2) tonnage by 10%; and (3) average price by $50/ton by December 31, 2016. Additional baseline data reported at the beginning of this project were:

- Total white wine grape production in 2013: 103,200 tons
- Average price for white wine grapes in 2013: $852/ton

By the time this final report was due, the 2016 harvest data were not yet available; thus the 2015 production and price data were used here:

- Total white wine grape production in 2015: 109,200 tons
- Average price for white wine grapes in 2015: $844/ton

These benchmark data demonstrate that total white wine grape production (tonnage) increased by 39% from 2011 through 2015, and thus markedly exceeded the proposed target of 10% growth by 2016. The average price for white wine grapes was the same in 2015 as it was in 2012. Thus the targeted $50/ton increase did not materialize. This was mainly due to some oversupply, especially of Riesling and Chardonnay, due to rapid industry expansion. Unfortunately, the latest data on white wine grape acreage are available only for 2011. No data for either 2016 or 2015 are currently available. The USDA-NASS vineyard acreage report for Washington was expected to be published in 2016 (it has been on a 5-year cycle), but has not yet been released. However, industry figures indicate that the total wine grape acreage in 2016 has increased to approximately 55,000 acres, which would be a 25% increase over 2011, consistent with the proposed target.

BENEFICIARIES

The Washington state wine industry stakeholders (both wine grape growers and wine producers) have benefited from the completion of this project. As outlined in the Goals and Outcomes Achieved section of this report above, the outputs generated from this project have been shared widely with most grower and winery stakeholders, which will contribute to the long-term economic and environmental sustainability of the wine industry, and will enhance the industry's competitiveness in both domestic and global markets. Moreover, key findings from this project have already been integrated in the PI's classroom teaching materials in the Washington State University viticulture and enology program. This program currently has 113 enrolled undergraduate students, most of who will embark on careers in the wine industry upon graduation.

At the start of the project, the wine industry in the state of Washington comprised over 350 growers and more than 750 wineries. The number of growers has remained approximately constant or increased slightly, but the number of wineries has grown to more than 900 by 2016. White wine grapes account for about half of the total wine grape production in Washington. As explained in Goals and Outcomes Achieved section of this report, the total white wine grape production has increased by about 31,000 tons or 39% between 2011 (baseline data) and 2015 (one year prior to project completion). Since the average price for white wine grapes has remained constant ($844/ton), the increase in tonnage translates to an increase in farm-gate value of more than $26 million per year. Given that 1 ton of grapes on average produces 756 bottles of wine, and assuming a conservative average bottle price of $10, the increase in white wine grape production translates into additional winery income of over $234 million per year.

LESSONS LEARNED

On the positive side, almost all of the project activities and goals were achieved. The project confirmed the initial hypothesis, namely that applying principles of deficit irrigation developed for red wine grapes to white wine grape production may result in wines that can be overly astringent or even bitter. The solution to this potential problem is also a negative conclusion of the project: minimizing astringency and bitterness in white wines requires an increase in the amount of irrigation water, especially early in the growing season. However, the project also found that implementing the irrigation method of partial rootzone drying, rather than the industry standard of regulated deficit irrigation, might have the potential to achieve the desired fruit composition outcomes without an increase in irrigation water supply. Testing this method was not part of the original project Work Plan, and the results are preliminary. However, these results are encouraging enough to have met with considerable industry interest and to warrant further research.

No unexpected outcomes or results affected the implementation of this project.

All but one of the activities and all goals were achieved (see the Goals and Outcomes Achieved section of report). However, as anticipated at the start of this project, some industry data required to estimate the Expected Measurable Outcomes were not available by the time this final report was submitted. This is partly due to the predetermined grant dates, which do not coincide with the wine industry production cycle. Grape harvest was just winding down by the time this report was submitted. Moreover, the USDA-NASS vineyard acreage report that had been expected for 2016 has yet to be released.

ADDITIONAL INFORMATION

Cash match: $102,000

The Washington Wine Commission, through its Wine Advisory Committee (WAC), provided a cash match of $34,000 per year. These funds were used as follows: salary and benefits for two technicians (1 month/year: $6,500; and 4 months/year: $21,700) and for undergraduate student interns (2 days/week for 3 months/year: $2,360) to help with data collection and harvest; irrigation system maintenance and field and lab supplies ($2,500); travel to field sites (24 trips x 70 miles x $0.56/mile: $940).

In-kind match: $76,204

Ste. Michelle Wine Estates (SMWE) committed two production vineyard blocks to conduct the field trials associated with this project. To facilitate independent control of irrigation applications, SMouradapted their existing irrigation system and dug trenches to lay pipes to each of the two blocks and along the headland of each block. SMWE also donated approximately 0.5 tons of fruit from each block for experimental winemaking in 2014, 2015, and 2016. They estimate their total in-kind contribution to be valued at $39,840 and distributed as follows: irrigation system alteration ($2,500); viticultural management and supervision ($11,450); labor ($14,450); fuel ($640); pesticides ($2,100); fertilizer ($350); fruit value ($8,350).

Washington State University provided $36,364 (20%) of the total requested funds for the unrecovered F&A cost as a cost-share to this project.

Gohil H., M. Keller and M. Moyer. 2016: On-farm vineyard trials: A grower's guide. Washington State University Extension Manual EM098e, 23 pp.

Ruiz Mariño U. 2015: Decision tool comparison based on evapotranspiration, soil, and plant water content to determine vineyard water requirement and improve irrigation strategies for white winegrape production. MS thesis, Geisenheim University, Germany (co-advisor: M. Keller).

Rochi L. 2015: Physiological responses of white grape berries to sunlight exposure. PhD thesis, University of Milan, Italy (co-advisor: M. Keller).

Zhang Y. and M. Keller. 2015: Irrigation scheduling and management for white wine grape production. Proc. 19th International Symposium GiESCO, Gruissan, France. Publications et Actualités Vitivinicoles. pp. 154-158.

Table 1. Description of irrigation treatments implemented in 2014, 2015, and 2016.

Phenology	Before budbreak	Budbreak to fruit set	Fruit set to veraison	Veraison to harvest	After harvest

<table>
<tr><td rowspan="7">Treat-
ment</td><td>T0</td><td rowspan="7">Replenish soil water content when necessary</td><td colspan="3">Irrigate to replace 100% crop evapotranspiration
(ET-based approach)</td><td rowspan="7">Replenish soil water content</td></tr>
<tr><td>T1</td><td colspan="3">Irrigate to maintain soil water content ≥16%
(soil-based approach)</td></tr>
<tr><td>T2</td><td colspan="3">Irrigate to maintain stem water potential ≥-0.7 MPa
(plant-based approach)</td></tr>
<tr><td>T3</td><td>Moderate stress [a]</td><td>Moderate stress</td><td>Moderate stress</td></tr>
<tr><td>T4</td><td>Moderate stress</td><td>Moderate stress</td><td>No stress [b]</td></tr>
<tr><td>T5</td><td>No stress</td><td>Moderate stress</td><td>No stress</td></tr>
<tr><td>T6</td><td colspan="3">Partial rootzone drying [c]</td></tr>
</table>

[a] For moderate stress, soil water content was between 12% and 16% (v/v), and stem water potential was between -1 MPa and -0.7 MPa.
[b] For no stress, soil water content and stem water potential were equal to or higher than 16% and -0.7 MPa, respectively.
[c] Irrigation was alternated when soil water content of drying side was equal to or less than 12%.

Table 2. Soil water content (θ_v), stem water potential (Ψ_s), and leaf gas exchange (A, photosynthetic rate; g_s, stomatal conductance, E, transpiration rate) by treatment for Chardonnay in 2014, 2015, and 2016. Treatments are described in Table 1. Different letters within rows indicate significant differences by Fisher's LSD test ($P < 0.05$). Rows without letters indicate no significant difference.

Parameter	**Irrigation treatment**						
	T0	T1	T2	T3	T4	T5	T6
2014							
θ_v (% v/v) (before fruit set)	17.4	16.9	16.8	16.5	16.9	17.9	17.5
(fruit set – veraison)	16.6 a	13.9 b	12.8 c	11.5 d	11.0 d	11.6 d	12.9 c
(veraison – harvest)	16.6 a	15.3 a	12.5 b	11.3 b	15.3 a	15.8 a	12.1 b
Ψ_s (MPa) (fruit set – veraison)	-0.5 a	-0.8 b	-0.8 b	-1.1 c	-1.1 c	-1.2 c	-0.9 b
(veraison – harvest)	-0.4 a	-0.5 a	-0.7 b	-1.0 c	-0.6 b	-0.7 b	-0.9 c
Preveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	14.5 a	14.4 a	12.4 ab	8.8 d	9.7 cd	9.8 cd	11.6 bc
g_s (mmol $m^{-2}s^{-1}$)	187 a	185 a	108 b	103 b	95 b	95 b	110 b
E (mmol $m^{-2}s^{-1}$)	4.7 a	4.6 a	3.3 b	2.8 b	2.8 b	2.8 b	3.2 b
Postveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	9.2 b	10.1 ab	9.0 b	13.3 a	10.7 ab	10.7 ab	9.5 b
g_s (mmol $m^{-2}s^{-1}$)	170 ab	150 ab	158 ab	208 a	150 ab	147 ab	143 b
E (mmol $m^{-2}s^{-1}$)	3.2	2.9	2.9	3.5	2.9	2.7	2.9
2015							
θ_v (% v/v) (before fruit set)	16.6 a	16.5 a	16.6 a	15.3 b	15.3 b	17.1 a	16.9 a
(fruit set – veraison)	13.8 a	14.1 a	13.5 a	11.0 c	10.7 c	11.4 c	12.2 b
(veraison – harvest)	12.7 b	13.7 ab	13.3 ab	11.0 c	14.9 a	14.9 a	12.2 bc
Ψ_s (MPa) (fruit set – veraison)	-0.9 b	-0.8 a	-0.9 b	-1.2 d	-1.3 d	-1.2 d	-1.1 c
(veraison – harvest)	-0.9 a	-0.9 a	-0.9 a	-1.3 c	-1.0 a	-1.0 a	-1.2 b
Preveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	12.8 b	14.0 a	13.4 ab	10.1 d	10.8 cd	11.1 cd	11.4 c
g_s (mmol $m^{-2}s^{-1}$)	255 a	275 a	263 a	157 b	190 b	190 b	195 b
E (mmol $m^{-2}s^{-1}$)	6.8 a	6.8 a	6.8 a	4.9 c	5.7 bc	5.7 bc	6.0 ab
Postveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	16.6 a	15.3 ab	16.4 a	12.2 c	14.8 abc	13.4 bc	15.0 ab
g_s (mmol $m^{-2}s^{-1}$)	248 a	230 a	263 a	145 c	193 b	180 b	216 b
E (mmol $m^{-2}s^{-1}$)	6.6 a	6.4 a	7.0 a	5.1 c	5.7 b	5.6 b	6.2 ab
2016							
θ_v (% v/v) (before fruit set)	15.5 b	17.0 a	16.7 ab	14.9 c	15.0 c	16.7 a	17.6 a

(fruit set – veraison)	16.2 a	14.9 b	15.0 b	12.4 d	12.0 d	13.1 cd	13.8 c
(veraison – harvest)	16.6 a	13.9 b	14.1 b	12.3 c	15.2 ab	15.0 ab	13.9 b
Ψ_s (MPa) (fruit set – veraison)	-0.7 a	-0.7 a	-0.7 a	-0.9 c	-0.9 c	-0.9 c	-0.8 b
(veraison – harvest)	-0.4 a	-0.6 b	-0.7 b	-0.9 d	-0.6 b	-0.6 b	-0.8 c
Preveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	17.4 a	16.1 a	16.7 a	13.6 b	16.4 a	13.7 b	15.9 a
g_s (mmol $m^{-2}s^{-1}$)	294 a	268 ab	278 a	179 d	222 c	177 d	237 bc
E (mmol $m^{-2}s^{-1}$)	6.9 a	6.6 a	6.7 a	5.1 b	6.0 ab	5.1 b	6.0 ab
Postveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	14.6 ab	15.2 ab	16.3 a	12.4 b	14.1 ab	13.7 ab	14.5 ab
g_s (mmol $m^{-2}s^{-1}$)	288 a	263 ab	270 ab	193 c	230 bc	225 bc	238 abc
E (mmol $m^{-2}s^{-1}$)	10.7 a	9.9 ab	9.6 ab	9.0 b	9.3 ab	9.0 b	9.6 ab

Table 3. Soil water content (θ_v), stem water potential (Ψ_s), and leaf gas exchange (A, photosynthetic rate; g_s, stomatal conductance, E, transpiration rate) by treatment for Riesling in 2014, 2015, and 2016. Treatments are described in Table 1. Different letters within rows indicate significant differences by Fisher's LSD test ($P < 0.05$). Rows without letters indicate no significant difference.

Parameter	**Irrigation treatment**						
	T0	T1	T2	T3	T4	T5	T6
2014							
θ_v (% v/v) (before fruit set)	21.5 b	18.8 c	21.1 b	20.6 bc	20.0 bc	23.8 a	19.2 c
(fruit set – veraison)	23.3 a	16.3 b	14.8 bc	14.2 cd	12.8 d	13.2 d	14.7 c
(veraison – harvest)	20.3 a	16.6 b	14.0 cd	12.5 d	16.2 b	15.4 b	14.0 cd
Ψ_s (MPa) (fruit set – veraison)	-0.4 a	-0.7 b	-0.7 b	-0.7 b	-0.8 c	-0.9 c	-0.8 c
(veraison – harvest)	-0.4 a	-0.5 a	-0.7 b	-1.0 c	-0.7 b	-0.7 b	-0.8 b
Preveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	18.6 a	16.0 ab	15.7 ab	16.8 ab	14.3 b	15.5 ab	16.8 ab
g_s (mmol $m^{-2}s^{-1}$)	220 a	165 bc	170 bc	195 ab	138 c	170 bc	188 ab
E (mmol $m^{-2}s^{-1}$)	5.7	4.6	5.1	5.2	4.4	5.2	4.9
Postveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	16.8 a	17.0 a	17.9 a	16.7 a	15.5 ab	13.3 b	15.8 ab
g_s (mmol $m^{-2}s^{-1}$)	303 a	250 bc	270 ab	255 bc	200 d	190 d	228 cd
E (mmol $m^{-2}s^{-1}$)	4.3 a	3.9 ab	4.1 a	4.0 ab	3.7 ab	3.0 b	3.6 ab
2015							
θ_v (% v/v) (before fruit set)	18.9 a	18.0 b	18.2 ab	16.2 c	16.9 c	18.1 ab	18.0 b
(fruit set – veraison)	18.0 a	15.4 b	15.6 b	13.4 c	13.5 c	13.4 c	14.2 c
(veraison – harvest)	16.6 a	15.8 a	14.7 ab	12.2 c	15.4 ab	14.8 ab	13.7 bc
Ψ_s (MPa) (fruit set – veraison)	-0.5 a	-0.7 b	-0.7 b	-0.9 c	-1.0 c	-0.8 c	-0.9 c
(veraison – harvest)	-0.6 a	-0.6 ab	-0.7 b	-1.0 c	-0.7 b	-0.6 ab	-0.9 c
Preveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	21.9 a	19.6 ab	20.3 ab	17.5 b	19.0 ab	19.4 ab	14.7 c
g_s (mmol $m^{-2}s^{-1}$)	298 a	233 b	248 ab	173 c	195 bc	205 bc	123 d
E (mmol $m^{-2}s^{-1}$)	7.0 a	5.7 bc	6.0 ab	5.0 c	5.4 bc	5.4 bc	3.9 d
Postveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	13.1 ab	15.3 a	14.8 a	11.5 b	15.0 a	13.8 ab	14.0 ab
g_s (mmol $m^{-2}s^{-1}$)	157 b	220 a	187 ab	130 c	203 ab	190 ab	173 ab
E (mmol $m^{-2}s^{-1}$)	4.1 a	4.7 a	4.5 a	3.3 b	4.5 a	4.4 a	4.2 a
2016							
θ_v (% v/v) (before fruit set)	16.9	17.4	17.3	16.6	16.8	17.1	17.1
(fruit set – veraison)	18.1 a	16.4 b	16.1 b	14.2 d	14.0 d	13.7 d	14.8 c
(veraison – harvest)	20.1 a	15.9 b	16.0 b	13.1 c	16.0 b	15.8 b	14.0 c
Ψ_s (MPa) (fruit set – veraison)	-0.5 a	-0.6 b	-0.6 b	-0.7 c	-0.7 c	-0.7 c	-0.7 c
(veraison – harvest)	-0.5 a	-0.6 b	-0.6 b	-0.8 c	-0.6 b	-0.6 b	-0.8 c
Preveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	17.4 a	16.7 a	17.2 a	16.3 a	14.8 b	16.3 a	16.1 ab
g_s (mmol $m^{-2}s^{-1}$)	263 a	223 ab	223 ab	195 b	180 b	198 b	195 b
E (mmol $m^{-2}s^{-1}$)	8.4 a	7.5 ab	7.7 ab	7.2 b	7.0 b	7.2 b	7.1 b

Postveraison gas exchange							
A (µmol $m^{-2}s^{-1}$)	14.5 a	14.2 a	14.4 a	11.2 b	13.9 a	13.7 a	13.1 ab
g_s (mmol $m^{-2}s^{-1}$)	220 a	222 a	198 a	143 b	198 a	200 a	185 a
E (mmol $m^{-2}s^{-1}$)	10.0 a	10.1 a	9.6 a	7.7 b	9.8 a	9.5 a	9.2 ab

Table 4. Canopy growth and density by treatment for Chardonnay in 2014, 2015, and 2016. Treatments are described in Table 1. Different letters within rows indicate significant differences by Fisher's LSD test (P < 0.05). Rows without letters indicate no significant difference.

Parameter	**Irrigation treatment**						
	T0	T1	T2	T3	T4	T5	T6
2014							
Leaf layers (veraison)	4.2 a	3.3 b	3.2 b	2.1 d	1.9 d	1.7 d	2.7 c
(harvest)	5.1 a	4.3 b	4.5 b	3.2 d	3.3 d	3.0 d	3.8 c
Fruit zone light (veraison, % ambient)	24 d	29 cd	31 bc	32 bc	34 ab	38 a	33 bc
(harvest, % ambient)	22 c	28 b	26 bc	31 ab	30 ab	35 a	28 b
Vigor (fruit set – harvest, mm d^{-1})	1.5 a	1.5 a	1.0 ab	1.0 ab	1.0 ab	0.6 b	1.3 a
Internode length (harvest, cm)	4.5	4.5	4.3	4.4	4.6	4.2	4.5
Lateral leaves per shoot (harvest)	2.9 a	2.1 b	1.4 c	1.5 c	1.6 c	1.5 c	1.6 c
Brown nodes per shoot (harvest)	10.4 ab	11.7 a	9.7 abc	8.3 bc	9.6 abc	7.2 c	10.1 ab
2015							
Leaf layers (veraison)	4.4 a	4.2 a	4.6 a	2.6 c	3.2 b	3.2 b	3.4 b
(harvest)	4.7 a	4.6 a	4.6 a	3.3 d	4.0 b	3.7 b	4.0 b
Fruit zone light (veraison, % ambient)	38 c	32 d	36 cd	47 a	47 a	44 ab	40 bc
(harvest, % ambient)	36 cd	34 d	34 d	45 a	45 a	42 ab	39 bc
Vigor (fruit set – harvest, mm d^{-1})	0.5 a	0.3 a	0.4 a	0.0 b	0.0 b	0.0 b	0.4 a
Internode length (harvest, cm)	4.5	4.5	4.4	4.2	4.3	4.1	4.4
Lateral leaves per shoot (harvest)	2.0	2.0	2.0	1.9	2.0	2.0	2.1
Brown nodes per shoot (harvest)	14 a	14 a	15 a	11 c	11 c	11 c	13 bc
2016							
Leaf layers (veraison)	3.9 b	4.7 a	4.8 a	2.9 e	3.5 cd	3.4 d	3.8 bc
(harvest)	4.5 bc	4.8 b	5.4 a	3.6 e	3.8 d	3.8 d	4.3 c
Fruit zone light (veraison, % ambient)	31 cd	21 e	26 de	39 a	36 abc	38 ab	33 bc
(harvest, % ambient)	25 cd	20 d	24 cd	34 a	31 ab	34 a	28 bc
Vigor (fruit set – harvest, mm d^{-1})	2.1 ab	3.0 a	2.2 ab	0.7 c	0.9 c	1.4 bc	2.5 ab
Internode length (harvest, cm)	4.3	4.6	4.3	4.5	4.5	4.6	4.7
Lateral leaves per shoot (harvest)	2.05 ab	2.18 a	2.06 ab	1.69 b	1.83 ab	2.02 ab	1.90 ab
Brown nodes per shoot (harvest)	15.8 abc	17.2 a	16.7 ab	13.5 c	14.2 bc	16.2 ab	16.4 ab

Table 5. Canopy growth and density by treatment for Riesling in 2014, 2015, and 2016. Treatments are described in Table 1. Different letters within rows indicate significant differences by Fisher's LSD test (P < 0.05). Rows without letters indicate no significant difference.

Parameter	**Irrigation treatment**						
	T0	T1	T2	T3	T4	T5	T6
2014							
Leaf layers (veraison)	4.6 a	3.1 b	3.1 b	2.7 c	2.4 c	2.7 c	2.8 bc
(harvest)	3.8 a	2.8 b	3.3 ab	2.9 b	2.9 b	3.0 b	2.9 b
Fruit zone light (veraison, % ambient)	30 c	49 a	44 ab	43 b	48 a	45 ab	45 b
(harvest, % ambient)	21 b	42 a	37 a	38 a	41 a	37 a	42 a
Vigor (fruit set – harvest, mm d^{-1})	4.2 a	1.4 b	1.7 b	1.9 b	1.4 b	1.4 b	1.4 b
Internode length (harvest, cm)	3.9	4.0	4.0	3.8	4.1	3.7	3.9
Lateral leaves per shoot (harvest)	2.0 a	1.7 b	1.7 ab	1.8 ab	1.8 ab	1.6 b	1.7 ab
Brown nodes per shoot (harvest)	11.4	9.9	10.8	12	10.7	10.5	11
2015							
Leaf layers (veraison)	5.6 a	4.6 b	4.7 b	3.5 d	3.8 cd	3.7 cd	4.0 c
(harvest)	5.0 a	4.6 b	4.4 b	3.5 d	3.8 cd	4.0 c	3.8 cd
Fruit zone light (veraison, % ambient)	35 c	58 ab	53 b	62 a	57 ab	56 b	56 b
(harvest, % ambient)	32 b	50 a	45 a	46 a	50 a	50 a	49 a
Vigor (fruit set – harvest, mm d^{-1})	3.0 a	0.6 b	1.0 b	0.4 b	0.5 b	0.4 b	0.5 b
Internode length (harvest, cm)	3.8	3.6	3.7	3.6	3.8	3.7	3.9
Lateral leaves per shoot (harvest)	2.2 a	1.6 b	1.9 ab	1.6 b	1.5 b	1.6 b	2.0 a

Brown nodes per shoot (harvest)	15 a	11 b	11 b	10 b	11 b	11 b	12 b
2016							
Leaf layers (veraison)	5.2 a	4.6 b	4.4 b	3.4 d	3.7 cd	3.9 c	4.4 b
(harvest)	5.1 a	4.2 bc	4.4 b	3.4 d	4.0 c	4.0 c	4.0 c
Fruit zone light (veraison, % ambient)	32 d	41 bc	37 c	44 ab	41 bc	47 a	44 ab
(harvest, % ambient)	32 b	37 ab	33 b	41 a	42 a	42 a	42 a
Vigor (fruit set – harvest, mm d^{-1})	1.5 a	0.7 bcd	1.0 b	0.4 cd	0.2 d	0.3 cd	0.7 bc
Internode length (harvest, cm)	3.8	3.9	3.8	3.9	3.7	3.8	3.8
Lateral leaves per shoot (harvest)	2.4 a	2.1 abc	2.2 ab	1.9 bc	1.8 c	1.9 bc	2.1 abc
Brown nodes per shoot (harvest)	15	13	15	12	13	14	13

Table 6. Yield components and fruit composition at harvest by treatment for Chardonnay in 2014, 2015, and 2016. Treatments are described in Table 1. Different letters within rows indicate significant differences by Fisher's LSD test (P < 0.05). Rows without letters indicate no significant difference.

Parameter	**Irrigation treatment**						
	T0	T1	T2	T3	T4	T5	T6
2014							
Yield (tons/acre)	7.5 a	7.2 ab	6.4 b	5.1 c	5.1 c	4.8 c	6.5 b
Berry weight (g)	1.44 a	1.37 b	1.30 c	1.2 e	1.04 f	1.04 f	1.24 d
Cluster weight (g)	112 a	111 a	106 a	85 bc	79 cd	73 d	95 b
Clusters per vine	76 ab	73 ab	68 b	69 ab	74 ab	75 ab	80 a
Fruit composition (harvest)							
TSS (Brix)	22.1	22.1	22.6	22.8	22.5	23.2	22.5
pH	3.44 ab	3.45 ab	3.45 ab	3.50 a	3.39 b	3.43 ab	3.49 ab
TA (g/L)	5.78 ab	5.84 a	5.44 bc	4.73 d	5.06 cd	4.87 d	4.94 d
2015							
Yield (tons/acre)	3.0 bc	4.5 a	3.6 b	2.0 d	1.9 d	2.4 d	2.7 c
Berry weight (g)	1.5 a	1.5 a	1.4 a	1.0 d	1.1 c	1.2 b	1.2 b
Cluster weight (g)	132 a	140 a	126 a	86 d	95 cd	116 b	102 b
Clusters per vine	26 cd	37 a	32 ab	27 bcd	22 d	24 d	31 bc
Fruit composition (harvest)							
TSS (Brix)	24.0 ab	24.2 ab	23.8 b	24.3 ab	23.9 b	24.3 ab	24.8 a
pH	3.85 bc	3.78 cd	3.75 d	3.97 a	3.97 a	3.89 ab	3.94 ab
TA (g/L)	4.1 a	4.4 a	4.5 a	3.3 b	3.4 b	3.7 b	3.3 b
2016							
Yield (tons/acre)	8.2 b	10.5 a	9.2 b	5.7 d	6.8 cd	5.8 cd	6.9 c
Berry weight (g)	1.74 a	1.66 ab	1.66 ab	1.31 e	1.47 cd	1.37 de	1.53 bc
Cluster weight (g)	171 b	189 a	179 ab	137 c	141 c	139 c	133 c
Clusters per vine	55 bc	63 a	59 ab	47 c	54 bc	47 c	59 ab
Fruit composition (harvest)							
TSS (Brix)	21.7 c	21.7 c	21.8 bc	22.7 ab	22.4 abc	23.1 a	22.1 bc
pH	3.64 bc	3.58 c	3.60 c	3.79 a	3.70 ab	3.76 a	3.64 bc
TA (g/L)	5.4 a	5.1 a	5.3 a	4.1 c	4.4 bc	4.3 c	4.9 ab

Table 7. Yield components and fruit composition at harvest by treatment for Riesling in 2014, 2015, and 2016. Treatments are described in Table 1. Different letters within rows indicate significant differences by Fisher's LSD test (P < 0.05). Rows without letters indicate no significant difference.

Parameter	**Irrigation treatment**						
	T0	T1	T2	T3	T4	T5	T6
2014							
Yield (tons/acre)	8.7 a	6.6 b	6.9 b	6.6 b	6.7 b	6.8 b	7.2 b
Berry weight (g)	1.47 a	1.30 c	1.31 c	1.31 c	1.24 d	1.24 d	1.36 b
Cluster weight (g)	108 a	79 c	109 a	102 ab	92 b	93 b	92 b
Clusters per vine	83 ab	86 a	65 c	66 c	75 abc	74 bc	80 ab
Fruit composition (harvest)							

TSS (Brix)	19.8	20.8	20.4	20.6	19.9	19.7	20.4
pH	3.14 ab	3.15 a	3.06 d	3.14 ab	3.10 bcd	3.07 cd	3.12 abc
TA (g/L)	7.6 a	6.7 bcd	7.1 ab	6.6 bcd	6.4 cd	6.9 bc	6.3 d
2015							
Yield (tons/acre)	7.5 a	4.8 bc	5.4 b	4.9 bc	4.6 bc	5.2 b	4.1 c
Berry weight (g)	1.3 a	1.2 c	1.3 b	1.0 e	1.0 e	1.1 d	1.1 d
Cluster weight (g)	116 a	79 c	92 b	79 cd	69 d	80 c	77 cd
Clusters per vine	66 ab	62 abc	60 bc	64 abc	69 a	67 ab	55 c
Fruit composition (harvest)							
TSS (Brix)	20.2	20.8	20.7	20.5	20.6	20.7	20.3
pH	3.42 ab	3.37 ab	3.45 b	3.32 a	3.42 ab	3.44 ab	3.35 ab
TA (g/L)	4.6 a	4.5 ab	4.1 b	4.2 ab	4.2 ab	4.4 ab	4.3 ab
2016							
Yield (tons/acre)	9.5 a	8.1 b	8.0 b	6.9 c	6.2 c	6.1 c	7.4 b
Berry weight (g)	1.32 a	1.21 ab	1.29 a	1.05 c	1.05 c	1.12 bc	1.21 ab
Cluster weight (g)	124 a	103 bc	106 b	94 bcd	86 d	93 cd	97 bcd
Clusters per vine	82 a	78 a	76 a	76 a	75 ab	67 b	78 a
Fruit composition (harvest)							
TSS (Brix)	20.3 a	19.2 c	20.3 a	19.4 bc	19.8 abc	20.1 ab	19.1 c
pH	3.30 a	3.20 b	3.26 ab	3.29 a	3.27 ab	3.29 a	3.22 ab
TA (g/L)	6.3 a	5.9 ab	5.6 bc	5.6 bc	5.6 bc	5.2 c	5.7 bc

Table 8. Annual amounts of irrigation water applied by treatment for Chardonnay and Riesling in 2014, 2015, and 2016. Treatments are described in Table 1.

Cultivar	**Year**	**Irrigation water (mm)**						
		T0	T1	T2	T3	T4	T5	T6
Chardonnay	**2014**	396	347	293	208	205	181	169
	2015	383	425	414	255	268	282	243
	2016	451	473	496	294	324	320	346
Riesling	**2014**	381	196	159	124	146	147	129
	2015	341	238	201	161	166	215	185
	2016	381	270	254	193	203	247	223

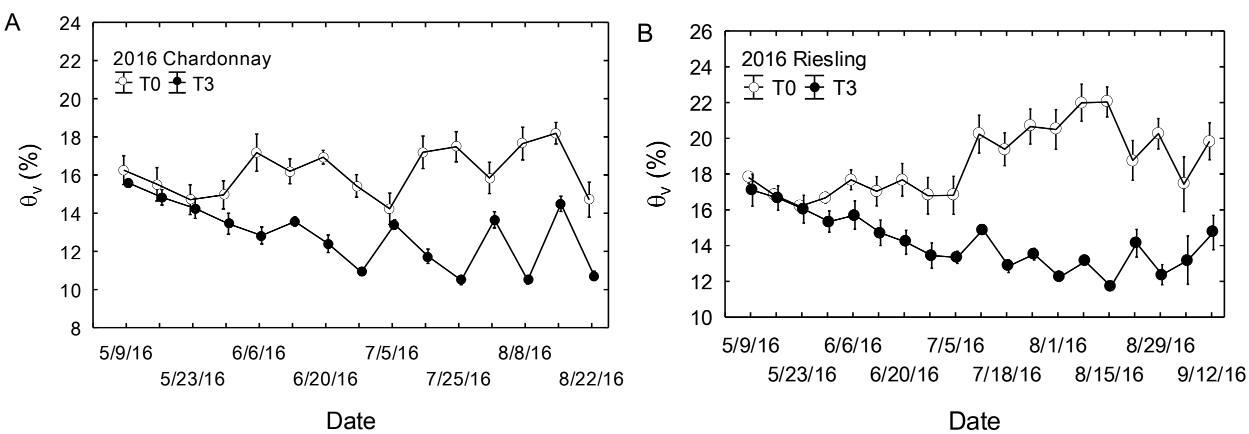

Figure 1. Examples of changes in soil moisture (θ_v) during the growing season for the two most extreme treatments (T0 and T3) in Chardonnay (A) and Riesling (B) in 2016.

CONTACT INFORMATION

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Project Title: Containing an Emerging Virus Disease Threatening Washington Vineyards

Partner Organization: Washington State University (WSU)

PROJECT SUMMARY

Virus diseases are recognized as one of the most serious impediments to the long-term sustainability of Washington's grape and wine industry (*Vinewise* [http://www.vinewise.org/] and *The Pest Management Strategic Plan for Washington State Wine Grape Production* [http://www.ipmcenters.org/pmsp/pdf/WA_WineGrape_PMSP_2014.pdf]). Viruses are known to induce a wide range of disorders, vine growth problems, graft incompatibility, reduced yield, delayed fruit maturity and poor quality of grapes. An industry-wide survey of stakeholders has identified management of viruses impacting fruit quality and vine health as one the highest research priorities for winemakers and wine grape growers (http://www.goodfruit.com/wine-grape-revelations/). A recent study (project #K952 funded by the SCBGP) on economic impacts of grapevine leafroll disease in a commercial Merlot vineyard, for example, indicated that a grower can lose up to $20,000 per acre over the 20-year period depending on the quantity of yield reduction and the scale of decline in fruit quality (*Is 'Grape Virus Tax' Hitting Your Pocketbook?* [http://www.goodfruit.com/is-grape-virus-tax-hitting-your-pocketbook/]).

A new graft-transmissible disease, designated as grapevine red blotch disease (GRBD), has been emerging as a serious threat to Washington's grape and wine industry (http://www.goodfruit.com/new-grape-disease-reduces-yields-quality/). A new virus with single-stranded DNA genome, designated as Grapevine red blotch-associated virus (GRBaV), was identified in grapevines (*Vitis vinifera* L.) showing red blotch symptoms. Previous studies have indicated significant negative impacts of GRBD on vine health, fruit yield and berry quality attributes in own-rooted wine grape cultivars Merlot and Cabernet Franc under commercial growing conditions. Preliminary surveys conducted during the 2013 season by Rayapati's team have shown that GRBD was present in other red-berried varieties, in addition to Merlot and Cabernet franc. However, the occurrence of GRBD and its effects on white grape varieties is unknown. Since symptoms of GRBD in red-berried cultivars overlap to a great extent under field conditions with those produced by grapevine leafroll disease (GLD), which is caused by grapevine leafroll-associated viruses that are distinct from GRBaV, growers had faced challenges in differentiating GRBD from GLD based on symptoms under field conditions. Thus, there is a critical need to generate science-based information about red blotch for practical applications in Washington vineyards.

Previous to the commencement of this project, no information was available on the prevalence of grapevine red blotch disease in Washington vineyards. Therefore, this project was initiated to (i) document the distribution of GRBD, relative to GLD, in Washington vineyards and (ii) measure impacts of the disease on fruit yield and berry quality in wine grape cultivars. In addition, the project was aimed at (i) disseminating science-based information through a variety of education and outreach programs for increased awareness of GRBD among growers and nurseries and (ii) strengthening grapevine clean plant and certification programs to facilitate the availability of virus-tested planting materials for growers. In the long term, the project outcomes are expected to foster sustainable growth of Washington's grape and wine industry that had an estimated $4.8 billion impact on Washington State's economy in 2013.

This project began in October 2013 and was not supported previously by the WSDA SCBGP. Activities of this project were carried out synergistically with research activities funded, in part, by other resources (the WSU Agricultural Research Center, the Wine Research Advisory Committee, the Washington Wine Commission, the Washington State Grape and Wine Research Program, WSDA Specialty Crop Block Grant Program, WSDA Grapevine Certification and Nursery Improvement Program, Washington State Commission on Pesticide Registration) for efficiency and effectiveness.

PROJECT APPROACH

The overall goal of the project was to document the distribution of GRBD in Washington using reliable diagnostic methods and assess impacts of the disease on fruit yield and berry quality in wine grape cultivars. Using the research-based knowledge generated during the project period, outreach and educational activities were conducted for increased awareness of GRBD among stakeholders and regulatory agencies to implement effective strategies for preventing the spread of this emerging disease.

- **Document the extent of distribution of grapevine red blotch disease in Washington vineyards.**

Activity: Test samples for the grapevine red blotch virus (geminivirus) and other grapevine viruses by high throughput molecular diagnostic methods.

During the project period covering 2014, 2015, and 2016 crop seasons, a total of 2,141 samples from 20 red- and 6 white-fruited wine grape (Vitis vinifera) cultivars were collected. These samples were collected in vineyard blocks planted in Yakima Valley, Horse Heaven Hills, Red Mountain and Walla Walla appellations. Names of appellations and grower vineyards were withheld from this report due to grower confidentiality. Leaf samples were collected from red-fruited cultivars exhibiting symptoms of GRBD and GLD symptoms and suspected for these two diseases. In the case of white-fruited cultivars, samples were collected randomly due to the lack of visible symptoms. In addition, growers have sent samples suspected for leaf roll or red blotch symptoms. These samples were extracted and tested by molecular diagnostic methods for the presence of Grapevine red blotch-associated virus (GRBaV) and grapevine leafroll-associated virus-3 (GLRaV-3). Virus-specific DNA fragments amplified in PCR assays from representative samples were cloned and nucleotide sequence determined. The sequences were analyzed using bioinformatics software programs to validate PCR results and confirm the presence of GRBaV and GLRaV-3 in grapevine samples.

Of the 2,141 samples tested, nearly 66.83% were positive for GLRaV-3 and 6% positive for GRBaV. Interestingly, about 8.73% of samples tested positive for both viruses. In contrast, nearly 18.4% were tested negative for both viruses. Some of these negative samples were tested positive for other grapevine viruses, such as GLRaV-4. It is likely that many of the samples tested negative could be showing 'symptoms' mimicking GRBD or GLD due to abiotic factors, such as nutrient deficiency, mechanical damage, mite feeding damage, etc. Nevertheless, the cumulative data over three seasons indicated that GLRaV-3 is the most predominant and wide spread compared to GRBaV. The results further indicated the presence of GLRaV-3 and GRBaV as mixed infections in some samples. The survey also revealed that symptoms of GLD and GRBD appear around véraison and are highly similar, though not identical, in red grape cultivars. Similar to GLD, white grape cultivars showed no apparent symptoms of GRBD. Consequently, symptoms of GRBD can easily be confused with GLD and virus-specific diagnostic assays are necessary for reliable diagnosis of these two disparate virus diseases under field conditions.

Activity: Conduct molecular analyses for confirmation of viruses associated with red blotch disease and improve sensitivity and specificity of diagnostic methods by real-time, quantitative PCR technology.

<u>Multiplex detection of viruses</u>: As stated above, visual diagnosis of GRBD and GLD in vineyards has become very difficult due to similar, though not identical, symptoms in many red-grape cultivars. Therefore, PCR-based diagnostic assays were used to test samples from individual vines to document whether a symptomatic vine is infected with GRBaV or GLRaV-3. Initially, individual samples were tested in separate molecular diagnostic assays for the presence of GRBaV (by PCR) and GLRaV-3 (by RT-PCR). To circumvent this time-consuming process, multiplex PCR assay, where samples from each symptomatic vine can be tested simultaneously for both viruses, was optimized to distinguish red blotch from leafroll. In 2016, this assay was further refined using 206 samples from seven red wine grape cultivars showing or suspected for GRBD and GLD symptoms. The results were compared with data from monoplex-PCR assay, where the same set of samples were tested for GLRaV-3 and GRBaV in separate assays. The data indicated 90.74 percent correlation between results obtained from monoplex- and multiplex-PCR assays. Additional studies are being pursued to further refine the multiplex-PCR assay (i.e. to achieve greater than 90% confidence levels) for detecting GLRaV-3 and GRBaV in single and co-infections. The multiplex PCR assay is expected to offer cheaper, faster, and reliable diagnostic services for nurseries to maintain virus-free vines in registered mother blocks and grape growers to establish new vineyards with 'clean' planting stock.

<u>Genetic makeup of the virus associated with grapevine red blotch disease</u>: Molecular analysis of the genome of GRBaV was carried out to gain a comprehensive understanding of the genetic makeup of the virus in Washington vineyards. Samples tested positive for GRBaV were selected from 15 wine grape cultivars and the entire genomic DNA of the virus was amplified by Rolling Circle Amplification and PCR. The DNA amplified from each cultivar was cloned separately and the nucleotide sequence determined. The derived nucleotide sequences were analyzed using bioinformatics software programs. The results indicated clustering of complete genome sequences of 36 virus isolates from Washington vineyards into two distinct groups, independent of cultivar and geographic location. Of the 36 sequences, 31 sequences obtained from the majority of wine grape cultivars clustered into one group and the other 5 into a second group. Further analyses of GRBaV

sequences is in progress to better understand their phylogenetic relationships with corresponding viral sequences from other grapevine-growing regions in the United States.

- **Document impacts of grapevine red blotch disease.**

During the project period covering 2014, 2015, and 2016 crop seasons, three red grape cultivars (Merlot, Syrah and Cabernet Sauvignon) planted in geographically separate grower vineyards were identified to assess impacts of GRBD on fruit yield and quality. For this purpose, grapevines with and without GRBD symptoms were tested for the presence of GRBaV and GLRaV-3 to ensure that vines with symptoms are positive for GRBaV and vines without symptoms are negative for both viruses. Subsequently, 15 to 20 vines with GRBD symptoms and equal number of disease-free vines were selected for each cultivar. To the extent possible, the same set of vines were used in all three seasons. Total fruit yield was collected from individual vines at the time of commercial harvest in September/October of 2014, 2015, and 2016. For measuring fruit quality, berries were collected randomly from five GRBD-affected and five disease-free vines and extracts used to measure total soluble solids (or sugars measured as °Brix), juice pH, titratable acidity and anthocyanin content of berries (a measure of berry color in red grape varieties). The data was analyzed by Student's t-test for significant differences between healthy and GRBD-affected vines.

A summary of the results are presented below:

- **Merlot**: In GRBD-affected vines, fruit yield per vine was reduced by 25.0%, 21.8%, and 9.53% in 2014, 2015, and 2016 seasons, respectively, compared to disease-free vines. Total soluble solids showed 11.90%, 10.03%, and 8.63% reduction in berries of GRBD-affected vines, respectively, in 2014, 2015, and 2016 seasons compared to berries from disease-free vines. There was no consistent difference in juice pH, titratable acidity and berry anthocyanins between GRBD-affected and disease-free vines across the three seasons.
- **Cabernet Sauvignon**: Fruit yield was reduced by 30.52% and 23.14% in GRBD-affected vines during 2015 and 2016 seasons, respectively, compared to disease-free vines (data was not collected during 2014 season). Total soluble solids showed 13.3% and 4.21% reduction in berries of GRBD-affected vines during 2015 and 2016 seasons, respectively, compared to disease-free vines. There was no consistent difference in juice pH, titratable acidity and berry anthocyanins between GRBD-affected and disease-free vines during the two seasons.
- **Syrah**: Fruit yield was reduced by 51.6%, 32.31%, and 52.9% during 2014, 2015, and 2016 seasons, respectively, in GRBD-affected vines compared to disease-free vines. Interestingly, no significant differences were observed in total soluble solids and berry anthocyanins between GRBD-affected and disease-free vines. In all three years, the pH of berry juice from GRBD-affected vines was higher by 3.58%, 8.86%, and 8.68% in 2014, 2015, and 2016 seasons, respectively, compared to pH of berry juice from disease-free vines.

The following conclusions were made based on the above results obtained during three consecutive seasons:

GRBD significantly affected fruit yield in all three red grape cultivars studied during this project period. However, the impact of GRBD on berry quality attributes was found to be variable between the three varieties. Total soluble solids were affected in berries of GRBD-affected Merlot and Cabernet Sauvignon vines. In contrast, no impact of GRBD was observed on total soluble solids in Syrah vines. The berry juice pH was higher in GRBD-affected Syrah vines, whereas no difference was observed in berry juice pH between GRBD-affected and disease-free Merlot and Cabernet Sauvignon vines. Berry skin anthocyanin content measured at the time of commercial harvest between GRBD-affected and disease-free vines showed no consistent pattern across the three seasons in Merlot, Cabernet Sauvignon and Syrah. These results suggest varying responses of red grape cultivars to infection with GRBD.

- **Conduct educational and outreach activities for increased awareness of grapevine red blotch disease among growers, nurseries, regulatory agencies and scientific community.**

The following presentations were made at grape and wine industry stakeholder meetings, workshops and professional scientific meetings to disseminate science-based information on viral diseases, with emphasis on grapevine red blotch disease:

Note: Naidu, R.A. and Naidu Rayapati are the same person, PI of this project.

2016:

i. Naidu, R.A. 2016. An overview of virus diseases in Washington vineyards. Washington State Grape Society annual meeting. November 10-11, 2016, Grandview, WA. (Oral).
ii. Adiputra, J., Swamy, P., Donda, B., Bagewadi, B., Natra, N. and Naidu, R.A. 2016. The prevalence of grapevine leafroll and red blotch diseases in Washington vineyards. Washington State Grape Society, November 10-11, 2016, Grandview, WA. (Poster).
iii. Naidu, R.A. 2016. It spread like…a virus: How leafroll spreads from old blocks to new plantings; What happens if I see something fishy and I want to test my vines? Industry Expansion Bottleneck: Where Will You Get Your Plants? October 27, 2016, The Clore Center, Prosser, WA. (Oral).
iv. Adiputra, J., Swamy, P., Donda, B., Bagewadi, B., Natra, N. and Naidu, R.A. 2016. The prevalence of grapevine leafroll and red blotch diseases in Washington vineyards. 2016 American Phytopathological Society Annual Meeting, June 30-August 3, 2016, Tampa, FL. (Poster).
v. Naidu, R.A. 2016. Managing viruses in Washington vineyards. WAVE 2016 Washington Advancements in Viticulture and Enology. WSU's Ste. Michelle Wine Estates Wine Science Center, Richland, WA. July 14, 2016. (Oral).
vi. Swamy, P. and Naidu, R.A. 2016. Impacts of grapevine leafroll and redblotch diseases in Washington vineyards. 67th American Society for Enology and Viticulture (ASEV) National Conference, June 27-30, 2016, Monterey, CA. (Oral).
vii. Adiputra, J., Swamy, P., Donda, B.P., Bagewadi, B., Natra, N., and Naidu, R.A. 2016. The relative distribution of leafroll and red blotch diseases in Washington vineyards. Washington Association of Wine Grape Growers 2016 Annual Meeting, Convention and Trade Show, February 9-11, 2016, Kennewick, WA.
viii. Swamy, P. and Naidu, R.A. 2016. Impacts of grapevine leafroll and redblotch diseases in commercial vineyards. Washington Association of Wine Grape Growers 2016 Annual Meeting, Convention and Trade Show, February 9-11, 2016, Kennewick, WA.
ix. Naidu, R.A. 2016. Grapevine virus diseases. Class lectures to WSU courses "HORT 421/521: Fruit Crops Management" in Spring 2016, "Hort 409: Seminar in Viticulture and Enology" in Fall 2016 and "PlP 300: Diseases of Fruit Crops" in Fall 2016.

2015:

i. Donda, B., Adiputra, J. and Naidu, R.A. 2015. Is it leafroll or red blotch? Washington Association of Wine Grape Growers 2015 Annual Meeting, Convention and Trade Show, February 10-13, 2015, Kennewick, WA. (Poster).
ii. Swamy, P., Donda, B., Adiputra, J. and Naidu, R.A. 2015. Is grapevine red blotch disease a bad omen for Washington vineyards? 2015 Annual Meeting, Convention and Trade Show, February 10-13, 2015, Kennewick, WA. (Poster).
iii. Adiputra, J., Donda, B. and Naidu, R.A. 2015. Grapevine leafroll and red blotch diseases in Washington vineyards. 66th American Society for Enology and Viticulture National Conference 2015, June 15-18, 2015, Portland, OR. (Poster).
iv. Swamy, P., Donda, B., Adiputra, J. and Naidu, R.A. 2015. Impact of grapevine red blotch disease in red-berried wine grape cultivars. 66th American Society for Enology and Viticulture National Conference 2015, June 15-18, 2015, Portland, OR. (Oral).
v. Naidu, R.A., Donda, B., and Adiputra, J. 2015. Grapevine leafroll and red blotch diseases in Washington State vineyards. Proceedings of the 18th Congress of the International Council for the Study of Virus and Virus-like Diseases of the Grapevine (ICVG), Ankara, Turkey, September 7-11, 2015, 38-39. (Oral).

2014:

i. Naidu, R. A. 2014. Grapevine Red blotch disease. G.S. Long Co., Inc. 2014 Grower Meeting, January 15, 2014, Yakima, WA. (Oral).
ii. Pack, J., Bagewadi, B. and Naidu, R.A. 2014. Studies on grapevine red blotch disease in Washington vineyards. Washington Association of Wine Grape Growers 2014 Annual Meeting, Convention and Trade Show, February 5-7, 2014, Kennewick, WA. (Poster).
iii. Naidu, R.A. 2014. An update on grapevine viruses in Washington vineyards. Washington Association of Wine Grape Growers 2014 Annual Meeting, Convention and Trade Show, February 5-7, 2014, Kennewick, WA. (Poster).

iv. Naidu, R. A. 2014. An update on grapevine viruses in Washington vineyards. WSU Academic Showcase, March 28, 2014, Pullman, WA. (Poster).
v. Pack, J., Bagewadi, B., and Naidu, R.A. 2014. Studies on grapevine red blotch disease in Washington vineyards. WSU Academic Showcase, March 28, 2014, Pullman, WA. (Poster).
vi. Richard Hoff (on behalf of Rayapati) 2014. Management strategies for red blotch virus. Ste. Michelle. Wine Estates Annual Grower meeting. May 20, 2014, Prosser, WA. (Oral).
vii. Naidu, R.A. 2014. Tasting – Red blotch & leafroll update. Ste. Michelle Wine Estates 2014 Winemaker Council Meeting. May 28, 2014, Prosser, WA. (Oral).
viii. Naidu, R.A. 2014. How to inspect a nursery and look for infected grape plants? WSDA Plant Science Program annual staff meeting. June 17, 2014, Prosser, WA. (Oral).
ix. Naidu, R.A. 2014. Grapevine virus diseases. WAWGG Summer Tour organized by the Washington Wine Industry Foundation. August 7, 2014, WSU-IAREC, Prosser, WA. (Oral).
x. Naidu, R.A. 2014. Grapevine virus diseases with emphasis on red blotch disease. WSU's professional certificate program in viticulture. September 14, 2014, Prosser, WA. (Oral).
xi. Naidu, R.A. 2014. Grapevine leafroll disease. Class lectures to WSU courses "HORT 421/521: Fruit Crops Management" in Spring 2014, "PlP 525: Field Plantt Pathology" in Summer 2014, "Hort 409: Seminar in Viticulture and Enology" in Fall 2014 and "PlP 300: Diseases of Fruit Crops" in Fall 2014.

Naidu Rayapati, PD of the project, performed overall management of the project and coordinated project activities, organized meetings with stakeholders, and submitted quarterly and annual progress reports. The technical personnel funded by the project, assisted by other members of Rayapati's program, conducted field and lab activities relevant for the project. Rayapati conducted outreach and educational activities disseminating project outcomes to grape and wine industry stakeholders and crop consultants, and students pursuing higher education at WSU. Both Rayapati and the project team presented results at professional scientific meetings.

This project is focused on wine grapes in Washington vineyards. Thus, potential benefits from this project are not anticipated to producers/processors of non-specialty crops.

GOALS AND OUTCOMES ACHIEVED

As described in the Project Approach section of this report, nearly 2,150 Samples were collected during 2014, 2015, and 2016 seasons from 20 red- and 6 white-fruited wine grape (Vitis vinifera) cultivars in eight AVAs (appellations) across Washington State. Samples were tested by molecular diagnostic assays for the presence of grapevine red blotch-associated virus (GRBaV) and grapevine leafroll-associated virus 3 (GLRaV-3). The results indicated that GLRaV-3 is far more widespread than GRBaV. A multi-plex PCR assay was optimized for simultaneous detection of GRBaV and GLRaV-3 in grapevine samples. The multiplex PCR assay is expected to offer cheaper, faster, and reliable diagnostic services for nurseries to maintain virus-free vines in registered mother blocks and grape growers to establish new vineyards with 'clean' planting stock. Despite its low incidence, GRBaV can cause significant negative impacts on fruit yield and quality in three red grape cultivars studied during this project period. The research-based outcomes of this project was shared with growers and industry stakeholders at industry-sponsored grower meetings for increased awareness of GRBD and to encourage growers to adopt best management practices, including effective sanitation practices and planting new vineyards with certified planting stock, for healthy vineyards.

Based on the data generated from this project, it is anticipated that at least two research articles will be published in peer-reviewed scientific journals during 2017/2018. A portion of the project data will be included in the doctoral thesis of a graduate student to be submitted in 2017 to Washington State University. In addition, a fact sheet is being developed on red blotch disease with an anticipated publication in 2017. The fact sheet will be distributed widely among the industry stakeholders for implementing best practices to manage red blotch disease in grower vineyards.

Project Activity	Timeline (*month and year*)	Accomplishments
Sample collection from wine grape cultivars in vineyards from representative AVAs.	Oct 2013; Jun-Oct 2014 & 2015.	Completed.
Test samples for the geminivirus and other grapevine viruses by high throughput molecular diagnostic methods.	Oct 2013-Oct 2015	Completed.
Conduct molecular analyses for confirmation of viruses and improve sensitivity and specificity of diagnostic methods by real-time, quantitative PCR technology.	Oct 2013-Dec 2014	Completed.
Collect and analyze data on fruit yield, berry quality and pruning weights in at least one red wine grape cultivar from two seasons.	Sept-Oct 2014, 2015; Feb 2014, 2015 (for pruning wt.).	Completed. The data was collected from three wine grape cultivars.
Develop and distribute bilingual factsheets on GRD.	Jun 2014-Oct 2015.	Expected to complete by end of 2017.
Conduct field days and/or tail-gate meetings to disseminate knowledge.	Jun-Sept 2014, 2015.	Completed.
Present results at grape industry annual meetings for the benefit of stakeholders.	Feb and Nov 2014, 2015, 2016.	Completed.

Previous to the commencement of this project, no information was available on the status of grapevine red blotch disease in Washington vineyards. The data generated during this project provided reliable estimates of the distribution of this disease relative to other viral diseases, such as grapevine leafroll disease. The project also generated information on impacts of red blotch disease on fruit yield and quality in three wine grape cultivars and disseminated science-based information for practical applications in vineyards. The project outcomes have met the two goals "Document the extent of the distribution of GRD in Washington vineyards" and "Increased awareness of red blotch disease among growers, nurseries, and regulatory agencies" listed in the proposal.

BENEFICIARIES

i. The project outcomes have benefited the Departments of Agriculture in Washington, Oregon and Idaho in harmonizing grapevine nursery certification programs across the Pacific Northwest. Eight members from the Departments of Agriculture of the three states and ten members of wine industry stakeholders from three states learned about the status of red blotch in Washington and methods available for the detection of grapevine red blotch-associated virus.

ii. Nearly 50 members of the grape industry in Washington, Idaho and Oregon benefited with presentations at the workshop "Industry Expansion Bottleneck: Where Will You Get Your Plants?" held on October 27, 2016.

iii. Project results shared during a presentation at the first meeting "WAVE 2016 Washington Advancements in Viticulture and Enology" on July 14, 2016, benefited nearly 60 members of Washington's grape and wine industry.

iv. Oral and poster presentations at stakeholder meetings such as the Washington Association of Wine Grape Growers (WAWGG) Annual Meeting, Convention and Trade Show (February 5-7, 2014; February 10-13, 2015; February 9-11, 2016 at Kennewick, WA) and Ste. Michelle Wine Estates 2014 Winemaker Council Meeting (May 28, 2014, Prosser, WA) and Washington State Grape Society Annual Meeting & Trade Show (November 12-13, 2015 and November 10-11, 2016, Grandview, WA) provided excellent opportunity to share project results on distribution and impacts of grapevine red blotch disease. Approximately 250 members of grape and wine grape industry stakeholders (consisting of grape growers, wine makers, crop consultants, vineyard managers and farm workers) and about 30 research and extension faculty and research associates, graduate students and undergraduate students in Viticulture & Enology Program from Washington State University and community colleges benefited from these presentations.

v. Presentation at the WSDA Plant Science Program annual staff meeting (June 17, 2014, Prosser, WA) benefited 18 members of the WSDA Plant Science Program in gaining new knowledge about impacts of grapevine virus diseases and the importance of maintaining virus-tested grapevines in certified nurseries.

vi. Presentation at the WAWGG Summer Tour (August 7, 2014, WSU-IAREC, Prosser, WA) benefited about 50 Spanish speaking vineyard employees in better understanding negative impacts of virus diseases on grape and wine quality.

vii. During the project period, about 75 students enrolled in WSU's professional certificate program in viticulture and nearly 150 undergraduate students enrolled in WSU courses "PlP 300: Diseases of Fruit Crops" and "HORT 409: Seminar in Viticulture & Enology" learned various aspects of grapevine red blotch and its impacts on plant health and fruit and wine quality during the class room teaching and associated field visits to grower vineyards.

As listed above, outcomes of the project were used in education and outreach programs for an increased awareness of grapevine red blotch disease and encourage Washington growers to use virus-tested clean planting stock for new vineyards. In the long term, the project outcomes are strengthening the WSDA Grapevine Nursery Certification Program and expected to foster sustainable growth of Washington's grape and wine industry that had an estimated $4.8 billion impact on Washington State's economy in 2013. Outcomes of the project have directly contributed to the funding priority of the WSDA SCBGP "Controlling Pests and Diseases" for advancing sustainability of Washington's grape and wine industry.

LESSONS LEARNED

The project personnel have pursued participatory collaborative approaches with grape and wine industry stakeholders to generate new knowledge about grapevine red blotch disease and its impacts on fruit yield and quality. It is important to share the science-based knowledge with stakeholders in a time-sensitive manner through various dissemination pathways for increased awareness of viral diseases and implement disease mitigation strategies in vineyards. A working relationship with Washington State Department of Agriculture is important to provide science-based knowledge for strengthening grapevine quarantine and certification programs to ensure that alien viruses and vectors are not introduced into the state. Overall, it is vital to have strong research-regulatory agency-industry partnerships to address key constraints such as viral diseases for maintaining healthy vineyards and advancing sustainability of wine grape production, a key economically important agricultural sector of Washington State.

Grapevine cultivars exhibit seasonal variations due to Genotype (G)-by-Environment (E) interactions. Thus, elucidating cultivar-and clonal-specific responses to viral infections during several seasons could help making short-term adjustments and long-term adaptations to viticulture practices for implementing sustainable strategies to mitigate negative impacts of viral infections due to climate change.

Project activities have been conducted according to the timeline described in the project. This was made possible with excellent team work between project personnel and productive collaborations with wine grape growers.

ADDITIONAL INFORMATION

Cash match for this project totaled $94,062.06.

Two research publications in peer-reviewed scientific journals during 2017/2018 will be published based on the data generated from this project. A portion of the project data will be included in a doctoral thesis of a graduate student to be submitted in 2017 to Washington State University. A fact sheet is being developed on red blotch disease with an anticipated publication in 2017. Funding support from the SCBGP will be duly acknowledged.

CONTACT INFORMATION

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Project Title: Spotted Wing Drosophila Management in Sweet Cherries

Partner Organization: Washington State University Tree Fruit Research & Extension Center (WSU TFREC)

PROJECT SUMMARY

This project addressed the IPM challenges caused by the invasion of a new pest of sweet cherry, spotted wing drosophila (SWD). Because the pest was first detected in Washington in 2009, much was unknown about its biology, ecology, and control. Prior to its arrival, the sweet cherry IPM program was in a relatively stable state: the development and implementation of GF-120 bait sprays for the other key pest, cherry fruit fly, allowed a program that had fewer broad-spectrum canopy sprays, and less disruption of secondary pests such as spider mites and aphids. The appearance of a new, direct pest caused a reversion to cover sprays during the entire period of fruit maturation (straw color through harvest).

Washington's sweet cherry industry has experienced substantial growth in the past 20 years, increasing from 11,000 acres to 35,000 acres. Cherries are a high value crop, with average gross returns at full production estimated at $23,429/acre. The value of Washington's production in 2015 was $436,918,000 (NASS 2016, Non-Citrus Fruit and Nut Summary). Low levels of fruit infestation by SWD can reduce packouts, and high levels can cause entire loads to be rejected, or crops abandoned in the field, thus control of this pest is imperative. Conversely, prophylactic sprays (with limited numbers of active ingredients) set the stage for insecticide resistance. Re-establishment of an IPM program, using monitoring, thresholds, and insecticide rotation must be achieved as soon as possible.

This project built on the work of Project K750, which established the basic phenology and distribution of SWD in the State of Washington. It explored the relative efficacy of monitoring tools, then in a fairly early stage of development. The goal in the previous project was to develop a tool and system for large-scale monitoring; this work has continued, but with the goal of developing a tool for site-specific monitoring. The current project also continued the work on establishing insecticide efficacy and the timing of cherry fruit susceptibility.

PROJECT APPROACH

The statewide monitoring program for SWD concluded at the end of the 2014 season (and with it, the regional alert system), providing five years of phenological data for Washington. These data are being used in a manuscript that describes seasonal occurrence and abundance of this pest in the Okanagan and Columbia River Basins in Washington, Oregon, and British Columbia. The significant trends from this dataset indicate the absence of winter activity (with the exception of very mild winters), low levels during the spring and summer building to a peak in the late summer and autumn. Other important factors identified are year-to-year variation, pesticide treatments, and the number of days < 5 °C (41 °F) during the winter months.

The advent of commercial traps and attractants has greatly changed the prospects for monitoring SWD. They bring a greater degree of standardization and ease of use compared to hand-made traps baited with apple cider vinegar. Four synthetic lures are available, which last at least 4 weeks in the field (although the drowning fluid still needs to be changed at each visit). Similarly, commercial traps are also available, designed for either liquid baits/drowning fluid or sticky cards. An ongoing problem with liquid-based traps is the large amount of by-catch (especially non-target Drosophila) and the amount of handling to process a sample; this characteristic has greatly impeded adoption of SWD monitoring after the conclusion of the statewide trapping program. An unexpected and exciting discovery was that the use of sticky cards (coupled with a synthetic lure) provides a more species-specific trap for SWD, while simultaneously biasing the capture to males, the sex most easily identified on the traps.

The unusually severe pest pressure during the 2015 season caused renewed concern among producers about SWD control. Because of this, determining the effective insecticides available for SWD control, along with their residual properties under Washington conditions, has been advanced considerably. Field and laboratory tests have identified the spinosyns and pyrethroids as the most residual materials, with carbaryl and malathion relatively short-lived. One athranilic diamide (Exirel) shows good activity against SWD. In preparation for a resistance management program, baseline sensitivities and preliminary screening of Washington populations has been accomplished for five SWD insecticides.

In the first year of the grant, the regional fieldmen (Wilbur-Ellis, Northwest Wholesale, GS Long, Cascade IPM, Northwest IPM, Columbia IPM, Quincy Farm Chemicals/McGregor and D&M consulting) provided substantial support in the form of trap sites in commercial orchards and weekly collection of the trap contents. The project was also supported by the WSDA commodity inspection service, which collected any Drosophila larvae found during cherry inspections. These were brought to either the WSDA office in Yakima or the TFREC in Wenatchee for identification. This program allowed an objective and industry-wide measurement of pest pressure and control program success. The Washington Tree Fruit Research Commission and the Washington Commission on Pesticide Registration continued their partnership in funding work on this pest throughout the life of the project.

The project does not benefit non-specialty crops.

GOALS AND OUTCOMES ACHIEVED

Activity #1. Monitor SWD activity in eastern Washington cherry orchards.
This activity was completed in December of 2014, concluding a 5-year study of distribution and phenology of SWD in Washington State.

Activity #2. Use monitoring information from #1 to power an alert system.
The web-based regional alert system was conducted in 2014, based on the data collected in the statewide trapping program. The trapping results were uploaded to a database daily, and alerts distributed via a mailing list when populations or packinghouse finds warranted this. The website http://www.tfrec.wsu.edu/pages/swd has had a total of 16,737 page views since inception, but due to the loss of IT support, yearly totals are not available.

Activity #3. Determine optimal traps and lures.
Trap and lure studies were conducted during the field seasons of 2014-2016, and have allowed us to make recommendations on effectiveness, selectivity, and ease of use of 3 baits, 4 lures, and 6 trap types. The Scentry lure has consistently provided the highest capture rate of SWD at both low and high densities. When placed in a liquid-based trap, the level of by-catch can reach high levels; however, when used with a sticky card, the by-catch is considerably reduced.

Activity #4. Determine efficiency of SWD detection.
Several tests were conducted to determine the efficiency of the fruit crush/brown sugar flotation method to detect low levels of SWD larvae. Large larvae were fairly easy to detect, but smaller larvae were recovered at a much lower rate.

Activity #5. Determine pesticide efficacy and longevity.
The length of effective residues was determined for Sevin, Malathion, Entrust, Delegate, Warrior, Altacor, Exirel, Dimilin, Rimon and an unregistered diamide (Harvanta). The two spinosyns (Delegate and Entrust) provided 14-21 days of residual control; Warrior provided about 10-14 days. Exirel and Harvanta provided good levels of control through 21 days, but mortality was never as high as with the former products. Dimilin and Rimon caused little direct mortality, but the former appeared to either sterilize the females or prevent development of eggs or larvae when adult females were exposed to residues.

Activity #6. Screen new compounds for SWD control.
One unregistered pesticide (Harvanta) was screened for efficacy against SWD, and appears to be promising for control (see activity #5). Several repellents and oviposition deterrents have been tested including butyl and methyl anthranilate and horticultural (petroleum) oil; of the materials tested, oil had the greatest effect on oviposition deterrence, although this is likely to be of short duration.

Activity #7. Determine efficacy of bait sprays.
GF-120 was tested in small insect cages in the laboratory to determine if all dilutions listed on the label were effective against SWD. For both males and females there was a high level of mortality by 48 h, with no significant difference between the most and least concentrated dilutions. The longevity of the droplets in the field was tested, with high level of mortality after 15 days when applied either by the GF-120 sprayer or hand pipetted on to the leaves. Bait tests with caged whole cherry trees were conducted in 2015 and 2016; the 2015 results were compromised by the cage design, but the 2016 results

indicate that both spinosad applied airblast and GF-120 sprays provided lower damage levels than the unsprayed checks, although statistical differences were not detected.

Activity #8. Screen SWD populations for insecticide resistance.
Baseline bioassays were completed on five insecticides (Delegate, Entrust, Malathion, Sevin and Warrior) using a reference colony (OSU1) collected in 2009. The probit analysis of these bioassay data were used to develop a diagnostic dose (2x the LC99). To date, 13 populations from Washington cherry orchards have been screened for all five pesticides using the diagnostic dose, which is designed to kill 100% of the insects tested. Of the 65 screenings, only 2 populations have had survivors: a conventional orchard (Malathion, Warrior) and an organic orchard (Delegate), both in Douglas County. The number of surviving females was low in these cases, but indicates that resistance management must be a priority in the future.

Activity #9. Provide real-time information to producers and consultants.
The website was active during the field seasons of 2014-2016, but the most meaningful real-time measurement (the regional trapping results) was only available in 2014. Alerts were sent out in 2015 to warn growers that pest pressure was high, but low pest pressure in 2016 resulted in no alerts being sent.

Activity #10. Provide research updates to producers and consultants.
A total of 27 presentations were given to producers, consultants, and colleagues to update them on SWD phenology, occurrence, monitoring practices, pesticide efficacy, and resistance.

Activity #11. Work with WSDA Inspection Service to identify Drosophila larvae found in samples.
The number of packinghouse finds positively identified as SWD in the three years of the study were 1 (2014); 236 (2015); and 11 (2016). The number of positive identifications was enhanced by the use of PCR in 2015/2016 for larvae that were not successfully reared to the adult stage, but these trends are generally reflective of pest pressure during those years. The extremely high number of finds in 2015 appeared to be an abnormally mild winter and early spring, which likely enhanced survival and development of SWD.

Activity #12. Prepare, submit reports.
Quarterly and annual reports on the outputs of this grant have been conveyed to the WSDA in a timely fashion.

The Outcome of the website was achieved in 2014 as expected, but the most meaningful data powering this website was discontinued due to the high cost of state-wide monitoring. In retrospect, this type of information would have been a powerful indicator of the pest pressure/damage that occurred in 2015, but the cost of broad-scale monitoring is considerable, and cannot be sustained without industry input. Conversely, the goal of producing a crop free from SWD was not realized in 2015, although the 2014 (1 find) and 2016 (11 finds) packinghouse finds were closer to this goal. Part of the difference may be due to enhanced detection, but it is equally likely that the pest pressure and the ability to apply control measures in a timely fashion are also contributory.

For the most part, the activities were accomplished to the extent made possible by field pressure of SWD. Year-to-year variation has been identified as a major factor governing SWD pest pressure, but the understanding of the factors that underlie this variation are only understood at a rudimentary level. Warmer winters appear to enhance earliness of capture, and subsequent pest pressure/damage during the season. Rainfall events during the maturation period may impede the ability of producers to apply control measures in a timely fashion, regardless of the knowledge of what the most efficacious and appropriate measures are.

The ability to summarize population densities on an area wide basis was lost after 2014. The baseline data from 2013 was 41 packinghouse finds of SWD, and by this metric, 2014 (1) and 2016 (11) were an improvement. However, WSU failed to accurately forecast a high-pressure year (2015), because user-friendly monitoring measures were not available or used. Future projects must address this deficit if WSU is to improve the IPM of SWD.

The website http://www.tfrec.wsu.edu/pages/swd was created in the fall of 2010 had >6,000 page views since its inception. The goal was to have >1,500 page views per growing season. The website has had a total of 16,737 page views since inception, but due to the loss of IT support, yearly totals are not available.

BENEFICIARIES

The beneficiaries of this project are the sweet cherry growers of Washington; they have more confidence in when and where SWD will occur, and have more tools with which to control and monitor this pest.

The website http://www.tfrec.wsu.edu/pages/swd was created in the fall of 2010 had >6,000 page views since its inception. The goal was to have >1,500 page views per growing season. The website has had a total of 16,737 page views since inception, but due to the loss of IT support, yearly totals are not available.

LESSONS LEARNED

The lessons learned have to do primarily with benefits of cooperation for the mutual benefits of all: the area wide trapping program provided a reasonable indicator of regional pest pressure, which producers could have used to modify their pest control programs. Failure to work cooperatively allowed the high levels of infestation in 2015. It should be noted that a cooperative program (grower-funded) continues in Oregon in the major cherry producing districts.

Two outcomes were unexpected as the result of this project. First, that the year-to-year variation could be so dramatic, or more specifically, result in such high pest pressure (e.g., 2015). The understanding up until the 2015 season was that this pest was manageable with 2-3 sprays. The second unexpected outcome was that a trap, rather than a lure, could be highly selective both for species and sex. That this may greatly facilitate future monitoring and merits further exploration.

Producing a crop free from SWD infestation may not be a realistic goal given the current level of establishment, despite early indications from what are now seen as lower pressure years. Year-to year variation in overwintering success or ability to apply protective sprays may reduce the options of the producers.

ADDITIONAL INFORMATION

The Washington Tree Fruit Research Commission provided cash match in in 2014 in the amount of $50,000 from a grant on SWD management, listed on the grant proposal. However, this work was also supported by a WTFRC grant for work on insecticide resistance in SWD in the amount of $55,575 (2014-2016), although this was not used formally as match in the grant. The Washington State Commission on Pesticide Registration contributed $14,481 (2015) and $16,356 (2016) to the project. These projects funded technicians, travel, supplies and students.

The in-kind match from WSU provided unrecovered indirect cost for PI Beers (salary + benefits) for 3 years.

CONTACT INFORMATION

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Project Title: Full Season Management of Powdery Mildew on Sweet Cherries

Partner Organization: Washington State University

PROJECT SUMMARY

The fungus Podosphaera prunicola, incitant of cherry powdery mildew, survives winter as chasmothecia. These propagules are formed from June-September in Washington orchards and nurseries. They are produced in profusion after orchard fungicide applications are terminated at harvest. The rationale for the project was to extend the "spray" season and to effectively deploy various fungicide modes of action in order to reduce the amount of survival inoculum. Studies on other crops demonstrated that a reduction in overwintered inoculum translates to delayed disease onset and reduced disease severity during the growing season. The purpose of the project was to identify fungicide modes of action and application timings that could be utilized to prevent chasmothecia formation and the potential for fungicide programs to disrupt cherry IPM programs.

The disease is the most serious IPM issue related to the production of sweet cherries in the Pacific Northwest. The disease is intensively managed until harvest but not afterwards. However, survival structures of the causal fungus are produced on foliage in great profusion after harvest. The rationale was to develop spray regimens that provide effective disease control, reduce the amount of survival inoculum, while following fungicide resistance management guidelines and "fitting" in established cherry insect management programs. Therefore, this project focused upon the effectiveness of various fungicide modes of action on chasmothecia formation, appropriate application timings to reduce chasmothecia formation, and the benefits of full season (pre and post-harvest) disease management on foliage using a combination of synthetic (resistance prone) and non-synthetic (less resistance risk). The expansion of chemical management options from 2000-2010 presented the potential for full season management without increasing the risk of fungicide resistance.

This project does not build on a previous SCBGP project.

PROJECT APPROACH

Objective 1. An industry-wide survey was conducted at the beginning of the project. Obtained using Survey Monkey baseline information on current industry practices for cherry mildew control, cost and effectiveness from the perspective of growers, shipper/packers, and industry chemical consultants. As of September 30 there were 11 responses, all from industry opinion leaders. Ninety per cent indicated that management of powdery mildew of cherry was important to their business; the majority of growers also indicated that most fungicide recommendations originate from chemical distributors and their associated field support personnel.

Objective 2: Various full season fungicide programs were evaluated for efficacy, sustainability (i.e. conformity to FRAC resistance management guidelines) and cost. These studies were conducted in research orchards and also at commercial orchards and nurseries. Most full season programs consisted of synthetic fungicide applications/alternations up to harvest followed by postharvest applications of contact fungicides. All studies of this nature conformed to FRAC resistance management guidelines and in most cases single or sequential application of narrow-range petroleum oils.

Objective 3. Various fungicide modes of action (and combinations thereof) were evaluated for their effects on chasmothecia numbers in both the orchard and nurseries. Orchard studies focused on the application timing of quinoxyfen (quinolone class) and penthiopyrad (SDHI) while nursery studies focused on the efficacy of individual modes of action (DMI, quinoline, SDHI, QoI, oil, and biological fungicides).

Objective 4. Various quinoxyfen programs were evaluated for reducing chasmothecia populations. In orchard studies, single quinoxyfen applications were evaluated in a "sliding" format in overall quinoxyfen:penthiopyrad programs. In nursery studies, single quinoxyfen treatments were applied according to multiple degree-day thresholds after the initial appearance of disease signs.

Objective 5. Print (Goodfruit Grower, Phytopathology, and EB 0419) and social media venues (Facebook: https://www.facebook.com/search/top/?q=Cherry%20Powdery%20Mildew) were established for ongoing outreach activities.

Objective 2 Approach and Results

Approach 1: Post-harvest application of narrow-range petroleum oils in experimental (WSU-IAREC; Tables 4-7) and commercial orchards (Hayden Farms, Pasco, WA; Tables 1-3).

Experimental Design:
The plot design for the trial at the cooperator's orchard uses rows as replications to minimize the impact of the study on the cooperator and allow for standard orchard spray practices. There are 6 rows of trees in each of four treatment blocks. Trees 1 and 6 are boundary rows. The center 4 trees are designated as Reps 1-4. The trees are Bing scion on Mazzard rootstock 1997.

Postharvest Treatments:
Control: No postharvest treatment
Treatment 1: Stylet Oil (1-2%): one application
Treatment 2: Stylet Oil (1-2%): two applications, second one 14 days after first
Treatment 3: Stylet Oil (1-2%): three applications, third one 14 days after second

a) Powdery mildew evaluation. Powdery mildew disease incidence and severity (% or leaves and leaf area infected) was recorded two weeks after the final oil application (July 27, 2015 and August 12, 2016).
b) Chasmothecia evaluation. Representative leaf samples were taken (9-26-2014, 9-23-2015, 9-21-2016) to assess the total number of chasmothecia and the viability of the ascospores contained within the chasmothecia in each treatment.
c) Mite evaluation. Sampling was conducted just prior to each treatment in order for mite populations to rebound as much as possible. Four reps of 25 leaves were collected from each treatment. Leaves were collected randomly at a height of 3 to 6 feet from the orchard floor from each treatment area and placed in a paper bag. The bags were placed in a cooler (with ice) for transport to the Wenatchee lab where they were placed in a cold room (34° F). Within 24 hours, the mites were collected from the leaves using a leaf brushing machine (Leedom, Mi-Wuk Village, CA) onto a revolving glass plate coated with undiluted dishwashing liquid. The composite sample on the plate was counted using a stereoscopic microscope. All stages and species of phytophagous and predatory mites were recorded, including the eggs and motile stages of European red mite (ERM), Panonychus ulmi (Koch); two-spotted spider mite (TSM), Tetranychus urticae (Koch); apple rust mite (ARM), Aculus schlechtendali (Nalepa); McDaniel spider mite (MCD), Tetranychus mcdanieli (McGregor); and western predatory mite (TYPH), Typhlodromus occidentalis (Nesbitt). The mites were grouped into pest or predatory mites except for the apple rust mite which was reported separately. Pest mites include ERM, TSM, and MCD and counted together as Tetrancychids. The predatory mite count includes only the TYPH. Sampling was terminated for the season when there were fewer than 5 mites/leaf counted.
Results and Discussion
a) Powdery mildew evaluation

In all years, significantly more disease was formed on the upper canopy than the lower canopy. In 2016, disease incidence in the upper portion of the trees in the treatment blocks ranged from 40 to 59% but only reached 15% in the untreated control. When lower and upper canopy ratings were combined, the untreated control had always significantly less powdery mildew than the oil treated trees. In general, an increase in oil applications resulted in an increase in powdery mildew disease incidence and severity. The same results were obtained in 2015 (22% disease incidence in the control versus 47%, 44% and 76% in Treatments 1, 2, and 3). In 2015 and 2016, disease severity was highest in the upper canopy of treatment block 3 (3x oil applications), with 4.7% in 2016 and 17% in 2015.

Table 1. Powdery mildew severity after final oil application in Pasco, WA

Powdery mildew Severity^ (%) 8-12-2016	Lower canopy		Upper canopy		Combined canopy	
Treatment 1 (1x oil)	0.21	A*	2.79	B	1.50	AB
Treatment 2 (2x oil)	0.98	A	3.52	AB	2.25	A
Treatment 3 (3x oil)	0.13	A	4.68	A	2.41	A
Control (No oil)	0.22	A	0.59	C	0.41	B

^ Severity = % leaf area infected by the fungus
*Values for a variable within a column followed by a common letter are not significantly different based on Tukey Kramer test (*P=0.05*)

b) Chasmothecia evaluation
Controlling the formation of chasmothecia, the overwintering structures of the powdery mildew fungus, is crucial for disease control. Moreover, reducing the viability of the ascospores contained within the chasmothecia can lead to a reduced amount of primary inoculum in the following season.

In 2016, neither the total amount of chasmothecia produced nor the ascospores viability was significantly increased or decreased by the application of post-harvest oil applications. No significant treatment differences were observed. In 2014 and 2015, Treatments 2 and 3 had the highest number of chasmothecia. In all three years, the untreated control had consistently the least amount of chasmothecia formed on leaves in the orchard, significantly less in 2014 (compared to Treatments 1 and 3) and 2015 (compared to Treatment 2) but not in 2016.

Table 2. Average number of chasmothecia formed on leaves and ascospore viability (%) – 2014 to 2016

2014	**Avg. Number of Chasmothecia**			**Ascospore Viability (%)**			
Treatment	**Lower canopy**	**Upper canopy**	**Combined canopy**	**Lower canopy**	**Upper canopy**	**Combined canopy**	
Treatment 1 (1x oil)	94.7	142.9	43.6 A	5.7	9.8	50.2	B
Treatment 2 (2x oil)	54.2	68.2	48.5 A	2.0	5.2	28.1	AB
Treatment 3 (3x oil)	17.0	231.9	38.7 A	1.5	11.9	9.3	B
Control (No oil)	37.6	88.4	45.3 A	4.5	8.4	21.0	AB

2015	**Avg. Number of Chasmothecia**				**Ascospore Viability (%)**			
Treatment	**Lower canopy**	**Upper canopy**	**Combined canopy**		**Lower canopy**	**Upper canopy**	**Combined canopy**	
Treatment 1	11.4	44	27.7	AB*	0.7	4.4	2.5	A

(1x oil)									*Values for a
Treatment 2 (2x oil)	12.8	71.2	42	A	1.6	4.9	3.2	A	variable within a column followed
Treatment 3 (3x oil)	12.1	46.3	29.2	AB	1.0	3.2	2.1	AB	by a common letter are not
Control (No oil)	8.0	29.5	18.7	B	0.4	2.6	1.5	B	significantly different based on

Tukey test (*P=0.05*)

*Values for a variable within a column followed by a common letter are not significantly different based on Tukey test (*P=0.05*)

2016	Avg. Number of Chasmothecia			Ascospore Viability (%)			
Treatment	**Lower canopy**	**Upper canopy**	**Combined canopy**	**Lower canopy**	**Upper canopy**	**Combined Canopy**	
Treatment 1 (1x oil)	26.8	60.4	43.6 A	3.3	5.4	4.3	A
Treatment 2 (2x oil)	44.8	52.3	52.3 AB	1.6	4.0	2.8	A
Treatment 3 (3x oil)	35.7	41.7	41.7 AB	2.5	2.9	2.7	A
Control (No oil)	19.1	71.6	19.1 B	3.6	2.4	3.0	A

*Values for a variable within a column followed by a common letter are not significantly different based on Tukey test (*P=0.05*)

c) Mite evaluation.

Mites/leaf values were calculated for each sampling date and analysis of variance (ANOVA) performed using SAS with confidence interval of 95% and means/Waller. Cumulative mite days (CMD) are calculated for treatment and both mites/leaf and CMD are presented graphically.

No rust mites were detected in the orchard. In 2015, the application of oil did significantly reduce the amount of Tetranychids (spider mites) per leaf during the peak season of the mites (mid to late August). The number of predatory mites never exceeded more than 1/ leaf and there was no significant difference between the treated and untreated blocks. In 2016, the untreated control had less Tetranychids and predatory mites/ leaf than the treated blocks, however, the difference was not significant.

Table 3.
2015: Pasco mites/ leaf

	Tetranychids/ leaf											
Treatment	11-Jun-15		9-Jul-15		23-Jul-15		6-Aug-15		20-Aug-15		3-Sep-15	
Control	0	A	0.07	A	0.18	A	4.56	A	8.18	A	0.22	A
1x oil	0	A	0.13	A	0.12	A	1.69	AB	0.75	B	0.17	A
2x oil	0.01	A	0.12	A	0.06	A	1.25	B	1.75	B	0.19	A
3x oil	0	A	0.01	A	0.04	A	0.79	B	2.24	B	0.5	A

	Predatory mites/ leaf											
Treatment	11-Jun-15		9-Jul-15		23-Jul-15		6-Aug-15		20-Aug-15		3-Sep-15	
Control	0.01	B	0	A	0	A	0	A	0.98	A	0.2	A

1x oil	0.04	A	0.02	A	0	A	0.03	A	0.87	A	0.58	A
2x oil	0.04	A	0	A	0	A	0.04	A	0.64	A	0.61	A
3x oil	0.02	AB	0	A	0	A	0	A	0.62	A	0.41	A

*Values for a variable within a column followed by a common letter are not significantly different based on Waller test (*P=0.05*)

2016: Pasco mites/ leaf

Tetranychids/leaf

Treatment	**22-Jun-16**		**7-Jul-16**		**21-Jul-16**		**4-Aug-16**		**18-Aug-16**		**1-Sep-16**		**15-Sep-16**		**29-Sep-16**	
Control	0	a	0	a	0.08	a	0	a	8.1	a	16.47	a	0	b	0	a
1x oil	0	a	0	a	0.14	a	0.03	a	23.77	a	23.1	a	0.04	b	0	a
2x oil	0	a	0	a	0.03	a	0.01	a	44.18	a	20.04	a	0.19	b	0	a
3x oil	0	a	0.01	a	0.02	a	0	a	14.71	a	24.31	a	3.94	a	0	a

Predatory mites/leaf

Treatment	**22-Jun-16**		**7-Jul-16**		**21-Jul-16**		**4-Aug-16**		**18-Aug-16**		**1-Sep-16**		**15-Sep-16**		**29-Sep-16**	
Control	0	a	0	a	0	a	0	a	0.22	a	0.2	a	0.11	a	0.05	a
1x oil	0	a	0	a	0	a	0.01	a	0	a	0.55	a	0.5	a	0.03	a
2x oil	0	a	0	a	0	a	0.01	a	0.31	a	0.44	a	0.64	a	0.05	a
3x oil	0	a	0	a	0	a	0	a	0.05	a	0.63	a	0.44	a	0.02	a

*Values for a variable within a column followed by a common letter are not significantly different based on Waller test (*P=0.05*)

Approach 2. Experimental orchard in Prosser, WA. These experiments addressed objectives 2-4.
Experimental Design:

The Prosser D-39 plot uses a completely randomized design for both the Sliding Quintec fungicide trial and the post-harvest oil application trial. Pre-harvest fungicides for control of cherry powdery mildew were applied in 11 treatments (four single tree reps), starting at shuck fall and biweekly thereafter. Each 'Bing' tree was randomly assigned a treatment and replicate number in each year. Post-harvest Stylet oil was applied twice, 14 and 28 days after the last fungicide application.

Table 4: Fungicide rotation and post-harvest oil application schedule in the experimental orchard in Prosser, WA. Pristine (pyracostrobin + boscalid), Fontelis (penthiopyrad; SDHI), and Quintec (quinoxyfen; quinolone MOA) represent 4 fungicide modes-of-action).

Treatment	**Shuck Fall**	**SF + 14**	**SF + 28**	**SF + 42**	**Post-Harvest 1**	**Post-Harvest 2**
1	Quintec	Quintec	Fontelis	Fontelis	**Oil**	**Oil**
2	Fontelis	Quintec	Quintec	Fontelis	**Oil**	**Oil**
3	Fontelis	Fontelis	Quintec	Quintec	**Oil**	**Oil**
4	Fontelis	Fontelis	Fontelis	Quintec	**Oil**	**Oil**
5	Quintec	Quintec	Quintec	Quintec	**Oil**	**Oil**
6	Quintec	Quintec	Quintec	Quintec	Untreated	Untreated
Control: 7	Untreated	Untreated	Untreated	Untreated	Untreated	Untreated
8	Fontelis	Fontelis	Fontelis	Fontelis	**Oil**	**Oil**
9	Fontelis	Fontelis	Fontelis	Fontelis	Untreated	Untreated
10	Pristine	Pristine	Pristine	Pristine	**Oil**	**Oil**
11	Pristine	Pristine	Pristine	Pristine	Untreated	Untreated

Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree).

a) Powdery mildew evaluation. Powdery mildew disease incidence and severity (% leaf area infected) was recorded after the last fungicide application and was repeated after the final oil application (July 3, 2014; June 15 and August 1, 2015; June 15 and July 14, 2016).

Evaluation of *chasmothecia production in experimental orchards*. Representative leaf samples were taken (9-26-2014, 9-25-2015, 9-14-2016) to assess the total number of chasmothecia and the viability of the ascospores contained within the chasmothecia in each treatment.

Table 5. Average number of chasmothecia formed on leaves and ascospore viability (%) after fungicide rotations and post-harvest oil applications – 2014 to 2016

			Avg. Number of Chasmothecia			Ascospore Viability (%)		
2014								
Fungicide rotation	**Post-harvest Oil**	**Treatment**	**Lower canopy**	**Upper canopy**	**Combined canopy**	**Lower canopy**	**Upper canopy**	**Combined canopy**
Q-Q-F-F	2x	1	112.8	315.0	214 B	4.3	21.5	13 A
F-Q-Q-F	2x	2	160.8	287.0	224 B	10.1	14.1	12 A
F-F-Q-Q	2x	3	121.8	189.0	155 C	12.2	14.0	13 A
F-F-F-Q	2x	4	36.8	158.5	98 C	3.3	13.3	8 A
Q-Q-Q-Q	2x	5	113.0	237.3	175 AB	10.6	8.5	10 A
Q-Q-Q-Q	none	6	337.0	337.3	337 A	19.0	16.5	18 A
none	none	7	213.3	296.8	255 B	31.9	24.5	28 A
F-F-F-F	2x	8	102.3	215.8	159 C	17.0	11.0	14 A
F-F-F-F	none	9	178.5	288.3	233 A	12.3	21.5	17 A
P-P-P-P	2x	10	108.8	143.0	126 D	16.3	17.4	17 A
P-P-P-P	none	11	52.0	111.3	82 D	10.5	7.0	9 A

*Values for a variable within a column followed by a common letter are not significantly different based on Tukey test (*P=0.05*). Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree).

2015			**Avg. Number of Chasmothecia**				**Ascospore Viability (%)**			
Fungicide rotation	**Post-harvest Oil**	**Treat ment**	**Lower canopy**	**Upper canopy**	**Combine d canopy**		**Lower canopy**	**Upper canopy**	**Combine d canopy**	
Q-Q-F-F	2x	1	40.0	163.8	102	B *	4.8	5.0	5	A
F-Q-Q-F	2x	2	279.3	305.0	292	A B	7.4	8.8	8	A
F-F-Q-Q	2x	3	117.0	275.5	196	A B	3.5	7.8	6	A
F-F-F-Q	2x	4	110.0	272.3	191	A B	3.5	7.0	5	A
Q-Q-Q-Q	2x	5	97.0	181.0	139	A B	2.4	5.3	4	A
Q-Q-Q-Q	none	6	249.0	283.3	266	A B	4.8	8.3	7	A

Untreated Control	none	7	331.5	274.5	303	AB	8.3	5.8	7	A
F-F-F-F	2x	8	119.5	155.0	137	A	3.3	8.8	6	A
F-F-F-F	none	9	437.8	506.8	472	AB	7.5	9.5	9	A
P-P-P-P	2x	10	130.0	244.3	187	AB	3.5	8.5	6	A
P-P-P-P	none	11	161.8	374.8	268	AB	5.3	6.3	6	A

*Values for a variable within a column followed by a common letter are not significantly different based on Tukey test (*P=0.05*). Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree).

2016			**Avg. Number of Chasmothecia**				**Ascospore Viability (%)**			
Fungicide rotation	**Post-harvest Oil^**	**Treatment**	**Lower canopy**	**Upper canopy**	**Combined canopy**		**Lower canopy**	**Upper canopy**	**Combined canopy**	
Q-Q-F-F	2x	1	21.3	15.0	21.3	B*	2.2	0.5	11.7	AB
F-Q-Q-F	2x	2	9.0	34.8	9.0	AB	0.0	5.0	4.5	AB
F-F-Q-Q	2x	3	25.8	61.8	25.8	AB	1.5	3.8	13.6	AB
F-F-F-Q	2x	4	51.5	41.5	51.5	AB	1.8	3.3	26.6	AB
Q-Q-Q-Q	2x	5	65.0	60.0	65.0	AB	7.8	5.6	36.4	A
Q-Q-Q-Q	none	6	38.3	141.0	38.3	AB	1.7	4.8	20.0	AB
Untreated Control	none	7	99.0	234.3	99.0	A	3.2	5.8	51.1	AB
F-F-F-F	2x	8	7.5	10.5	7.5	B	0.0	0.6	3.8	B
F-F-F-F	none	9	10.0	17.3	10.0	B	1.0	3.0	5.5	AB
P-P-P-P	2x	10	18.3	52.3	18.3	AB	1.5	3.3	9.9	AB
P-P-P-P	none	11	33.0	79.8	33.0	AB	6.3	5.3	19.6	AB

*Values for a variable within a column followed by a common letter are not significantly different based on Tukey test (*P=0.05*). Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree).

c) Mite evaluation. Same as described for the commercial orchard in Pasco, WA.

Table 6. 2015: Experimental orchard Prosser, Mites/ leaf

2015	**Tetranychids/leaf**											
Treatment	**18-Jun**		**16-Jul**		**30-Jul**		**13-Aug**		**28-Aug**		**10-Sep**	
1	0.02	ab*	0.63	b	1.2	cd	10.63	abc	7.71	a	0.02	b
2	0	b	0.53	b	0.52	e	9.25	abc	7.7	a	0.05	ab
3	0	b	0.33	b	0.74	cde	6.12	c	9.73	a	0.08	ab
4	0.02	ab	0.71	b	0.78	cde	13.55	a	10.2	a	0.08	ab
5	0.07	a	0.56	b	0.96	cde	7.5	bc	10.19	a	0.15	a
6	0.01	b	0.77	b	0.81	cde	8.61	abc	13.82	a	0.02	b
Untreated Control: 7	0.05	ab	0.43	b	1.32	bc	12.19	ab	7.55	a	0.02	b
8	0.02	ab	0.56	b	0.62	de	7.21	bc	8.7	a	0.01	b
9	0.01	b	1.19	ab	2.35	a	12.76	ab	11.62	a	0.01	b
10	0.04	ab	0.76	b	0.47	e	6.14	c	7.41	a	0	b
11	0	b	2.03	a	1.76	ab	11.08	abc	7.9	a	0	b
	Predatory mites/leaf											

Treatment	18-Jun		16-Jul		30-Jul		13-Aug		28-Aug		10-Sep	
1	0	a	0	a	0	a	0.11	a	0.01	a	0.04	b
2	0	a	0	a	0	a	0.02	a	0.05	a	0	ab
3	0	a	0	a	0	a	0.11	a	0.02	a	0.02	ab
4	0	a	0	a	0.01	a	0.02	a	0.05	a	0.03	ab
5	0	a	0	a	0.01	a	0.06	a	0.1	a	0.04	a
6	0	a	0	a	0.03	a	0.07	a	0.03	a	0.08	ab
Untreated Control: 7	0	a	0	a	0.02	a	0.01	a	0.02	a	0.06	ab
8	0	a	0	a	0.01	a	0.12	a	0	a	0.05	b
9	0	a	0	a	0.03	a	0.12	a	0.01	a	0.07	b
10	0.01	a	0	a	0.01	a	0.05	a	0.04	a	0.02	ab
11	0	a	0	a	0	a	0.13	a	0.04	a	0.05	ab
	Apple rust mites/leaf											
Treatment	**18-Jun**		**16-Jul**		**30-Jul**		**13-Aug**		**28-Aug**		**10-Sep**	
1	0	a	0	a	0	a	0	a	0	a	0	a
2	0	a	0	a	0	a	0	a	0	a	0	a
3	0	a	0	a	0	a	0	a	0	a	0	a
4	0	a	0	a	0.2	a	0	a	0	a	0	a
5	0	a	0	a	0	a	0	a	0	a	0	a
6	0	a	0	a	0	a	0	a	0	a	0	a
Untreated Control: 7	0	a	0	a	0	a	0	a	0	a	0	a
8	0	a	0	a	0	a	0	a	0	a	0	a
9	0	a	0	a	0	a	0	a	0	a	0	a
10	0	a	0	a	0	a	0	a	0	a	0	a
11	0	a	0	a	0	a	0	a	0	a	0	a

*Values for a variable within a column followed by a common letter are not significantly different based on Waller test (*P=0.05*). Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree).

Table 7, 2016: Experimental orchard Prosser, Mites/ leaf

	Tetranychids/leaf															
Treatment	**16-Jun**		**30-Jun**		**14-Jul**		**28-Jul**		**11-Aug**		**25-Aug**		**8-Sep**		**22-Sep**	
1	0	a	0	a	0	a	0	a	0.01	a	0.12	a	0	a	0	a
2	0	a	0	a	0	a	0	a	0	a	0.05	a	0.02	a	0	a
3	0	a	0	a	0	a	0	a	0.02	a	0.04	a	0.03	a	0	a
4	0	a	0	a	0	a	0	a	0	a	0.02	a	0.01	a	0	a
5	0	a	0	a	0	a	0	a	0.01	a	0.03	a	0	a	0	a
6	0	a	0	a	0	a	0	a	0	a	0.04	a	0.01	a	0	a
Untreated Control: 7	0	a	0	a	0	a	0	a	0	a	0.09	a	0	a	0	a
8	0	a	0	a	0	a	0	a	0.01	a	0.03	a	0	a	0	a
9	0	a	0	a	0	a	0	a	0.02	a	0.1	a	0	a	0	a
10	0	a	0	a	0	a	0	a	0	a	0.25	a	0.03	a	0	a
11	0	a	0	a	0	a	0	a	0	a	0.02	a	0.01	a	0	a
	Predatory mites/leaf															

Treatment	16-Jun		30-Jun		14-Jul		28-Jul		11-Aug		25-Aug		8-Sep		22-Sep	
1	0.01	a	0	a	0	a	0	a	0.02	a	0.3	abcd	0.57	a	0.13	a
2	0	a	0	a	0	a	0	a	0	a	0.06	d	0.37	a	0.21	a
3	0	a	0	a	0	a	0	a	0	a	0.07	cd	0.91	a	0.11	a
4	0	a	0	a	0	a	0	a	0.01	a	0.31	abc	0.4	a	0.15	a
5	0.02	a	0	a	0	a	0.01	a	0.09	a	0.24	bcd	0.49	a	0.05	a
6	0	a	0	a	0	a	0	a	0	a	0.1	cd	0.67	a	0.14	a
Untreated Control: 7	0	a	0	a	0	a	0	a	0.01	a	0.5	a	0.56	a	0.16	a
8	0	a	0	a	0	a	0	a	0	a	0.42	ab	1.26	a	0.13	a
9	0	a	0	a	0	a	0	a	0	a	0.37	ab	0.53	a	0.02	a
10	0	a	0	a	0	a	0	a	0.01	a	0.22	bcd	0.49	a	0.12	a
11	0	a	0	a	0	a	0	a	0.02	a	0.2	bcd	0.81	a	0.13	a

	Apple rust mites/leaf															
Treatment	**16-Jun**		**30-Jun**		**14-Jul**		**28-Jul**		**11-Aug**		**25-Aug**		**8-Sep**		**22-Sep**	
1	0.2	b	0	a	0	a	15.0	ab	117.8	ab	28.2	a	15.8	b	0	a
2	0.6	b	0	a	0	a	9.0	b	91.4	b	81.8	a	36.8	ab	0.4	a
3	0.6	b	0	a	0	a	13.2	ab	108.8	ab	77.2	a	66.2	a	0	a
4	0	b	0	a	0	a	12.6	ab	100.1	ab	73.6	a	10.2	b	0	a
5	2.4	ab	0	a	0	a	7.8	b	79.2	b	60.4	a	26.6	ab	1	a
6	4.8	a	0	a	0	a	21.6	ab	121.6	ab	59.2	a	15.0	b	0.8	a
Untreated Control: 7	0	b	0	a	0	a	47.6	a	150.0	ab	94.0	a	14.6	b	0	a
8	0.4	b	0.2	a	0	a	7.0	b	55.2	b	100.8	a	13.6	b	0	a
9	0	b	0	a	0.4	a	23.8	ab	201.1	a	120.8	a	13.0	b	0	a
10	0.2	b	0	a	0	a	19.6	ab	112.0	ab	106.2	a	12.2	b	0	a
11	0.8	b	0	a	0	a	38.4	ab	145.6	ab	45.4	a	4.0	b	0	a

Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree). *Values for a variable within a column followed by a common letter are not significantly different based on Waller test (*P=0.05*)

Approach 2: Pre-harvest fungicide rotations using Quintec (Tables 8-10)
A)Experimental orchard in Prosser, WA

Table 8, 2014: Effect of fungicide rotations on sweet cherry powdery mildew incidence and severity on leaves - 2014

2014 TMT #	**Pre-harvest Fungicide rotation***	**Powdery mildew Severity (%)****					
		Upper canopy		**Lower canopy**		**Combined**	
1	Q-Q-F-F	65	AB	14	BC	40	AB
2	F-Q-Q-F	47	AB	13	C	30	B
3	F-F-Q-Q	55	AB	18	BC	37	AB
4	F-F-F-Q	40	B	15	B	28	B
5	Q-Q-Q-Q	44	AB	31	AB	38	AB
6	Q-Q-Q-Q	53	AB	27	ABC	40	AB
8	F-F-F-F	49	AB	20	BC	35	B
9	F-F-F-F	53	AB	27	ABC	40	AB

10	P-P-P-P	60	AB	26	ABC	43	AB
11	P-P-P-P	45	AB	11	C	28	B
7	None	68	A	40	A	54	A

*Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree). Fungicide application dates: 4-30, 5-14, 5-28, 6-10-2014.
** Disease evaluation date: 7/1/2014. Results are averages of four single tree replicates. Values for a variable within a column followed by a common letter are not significantly different based on Tukey's HSD test (*P=0.05*).

Table 9, 2015: Effect of fungicide rotations on sweet cherry powdery mildew and severity on foliage - 2015

2015 TMT #	**Pre-harvest**	**Powdery mildew Severity (%)**					
	Fungicide rotation*	**Upper canopy**		**Lower canopy**		**Combined**	
1	Q-Q-F-F	22	C	18	A	20	AB
2	F-Q-Q-F	21	C	10	A	15	B
3	F-F-Q-Q	21	C	5	A	13	B
4	F-F-F-Q	39	AB	8	A	23	AB
5	Q-Q-Q-Q	29	BC	10	A	19	AB
6	Q-Q-Q-Q	32	BC	6	A	19	AB
8	F-F-F-F	32	BC	4	A	18	B
9	F-F-F-F	24	BC	14	A	19	AB
10	P-P-P-P	19	C	12	A	16	B
11	P-P-P-P	22	C	8	A	15	B
7	None	50	A	14	A	32	A

*Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree). Fungicide application dates: 4/23/2015, 5/7/2015, 5/21/2015, 6/4/2015.
** Results are averages of four single tree replicates. Values for a variable within a column followed by a common letter are not significantly different based on Tukey's HSD test (*P=0.05*).

Table 10, 2016: Effect of fungicide rotations on sweet cherry powdery mildew incidence severity on leaves - 2016

2016 TMT #	Pre-harvest	Powdery mildew Severity (%)					
	Fungicide rotation*	**Upper canopy**		**Lower canopy**		**Combined**	
1	Q-Q-F-F	19.2	A	7.4	AB	13.3	AB
2	F-Q-Q-F	13.6	A	1.4	B	7.5	B
3	F-F-Q-Q	16.8	A	4.6	B	10.7	AB
4	F-F-F-Q	10.6	A	3.8	B	7.2	B
5	Q-Q-Q-Q	20.4	A	4.3	B	12.4	AB
6	Q-Q-Q-Q	26.0	A	4.3	B	15.1	AB
8	F-F-F-F	11.6	A	2.1	B	6.8	B
9	F-F-F-F	12.1	A	2.5	B	7.3	B
10	P-P-P-P	16.2	A	2.9	B	9.5	AB
11	P-P-P-P	17.4	A	5.7	B	11.5	AB

7	None	21.4	A	15.2	A	18.3	A

*Q = Quintec 250SC, 7 fl oz/A, F = Fontelis, 20 oz/A, P = Pristine, 14.5 oz/A. Applied to run-off (400 gal/A = 1.5 gal per tree). Fungicide application dates: 4/21/2016, 5/5/2016, 5/20/2016, 6/2/2016.
** Results are averages of four single tree replicates. Values for a variable within a column followed by a common letter are not significantly different based on Tukey's HSD test (*P=0.05*).

Objective 3. Approach and Results. Various (FRAC Groups 3, 7, 11, and 13) fungicide modes of action were evaluated for their potential to reduce the amount of chasmothecia produced on infected foliage. All mode-of-action experiments were conducted in cherry nurseries in Central Washington (Tables 11-18).

Table 11. List of fungicides used in objective 3.

Fungicide – Trade name	**Common Name**	**FRAC Number**	**Chemical Class**	**Mode of action**
Quintec	quinoxyfen	13	aryloxyquinoline	Mechanism unknown
Fontelis	penthiopyrad	7	SDHI	Complex II: succinate dehydrogenase
Procure	triflumizole	3	DMI-imidazole	C14-demethylase in sterol biosynthesis (*erg11/cyp51*)
Serenade	*Bacillus subtilis*	44	microbial	Microbial disruptors of pathogen cell membranes
Luna Sensation	fluopyram/trifloxystrobin	11/7	Qol and SDHI	Complex III: cytochrome bc1 (ubiquinol oxidase) at Quinone outside site (*cyt b* gene)/ Complex II: succinate dehydrogenase
Luna Privilege	fluopyram	7	SDHI	Complex II: succinate dehydrogenase
GEM	triflloxystrobin	11	Qol	Complex III: cytochrome bc1 (ubiquinol oxidase) at Quinone outside site (*cyt b* gene)/

Products were applied at the following rates (sprayed to run-off = 400 gal/A): Quintec 250SC, 7 fl oz/A; Fontelis, 16 oz/A; Luna Sensation500C 5 oz/A; Serenade Optimum 16 oz/A; Procure480SC 16 oz/A; Luna Privilege 2.82 fl oz/A; GEM500SC 3.8 fl oz/A.

Table 12. Nursery Trial 1: Fungicide application schedule 2014 and 2015 (in Quincy, WA)

TMT #	**1st Application**	**2nd Application**	**3rd Application**	**4th Application**	**5th Application**
1	Quintec	Quintec	Quintec	Quintec	Quintec
2	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis
3	Procure	Procure	Procure	Procure	Procure
4	Serenade	Serenade	Serenade	Serenade	Serenade
5	Luna Sensation	Luna Sensation	Luna Sensation	Luna Sensation	Luna Sensation
6	Luna Sensation	Serenade	Luna Sensation	Serenade	Luna Sensation
7	Quintec	Quintec	Fontelis	Fontelis	Fontelis
8	Fontelis	Quintec	Quintec	Fontelis	Fontelis
9	Fontelis	Fontelis	Quintec	Quintec	Fontelis
10	Fontelis	Fontelis	Fontelis	Quintec	Quintec
11	Fontelis	Fontelis	Fontelis	Fontelis	Quintec

12	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis
13	Quintec	Procure	Quintec	Procure	Quintec
14	Untreated	Untreated	Untreated	Untreated	Untreated

Table 13. Fungicide application schedule **2016 (in Moses Lake, WA)** (Note: Treatment 2 and 4 were changed).

TMT #	**1st Application**	**2nd Application**	**3rd Application**	**4th Application**	**5th Application**
1	Quintec	Quintec	Quintec	Quintec	Quintec
2	GEM	GEM	GEM	GEM	GEM
3	Procure	Procure	Procure	Procure	Procure
4	Luna Privilege	Luna Privilege	Luna Privilege	Luna Privilege	Luna Privilege
5	Luna Sensation	Luna Sensation	Luna Sensation	Luna Sensation	Luna Sensation
6	Luna Sensation	Serenade	Luna Sensation	Serenade	Luna Sensation
7	Quintec	Quintec	Fontelis	Fontelis	Fontelis
8	Fontelis	Quintec	Quintec	Fontelis	Fontelis
9	Fontelis	Fontelis	Quintec	Quintec	Fontelis
10	Fontelis	Fontelis	Fontelis	Quintec	Quintec
11	Fontelis	Fontelis	Fontelis	Fontelis	Quintec
12	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis
13	Quintec	Procure	Quintec	Procure	Quintec
14	Untreated	Untreated	Untreated	Untreated	Untreated

Table 14. Powdery mildew severity in fungicide mode-of-action studies in Central WA nurseries 2014.

2014	**Powdery Mildew Disease Severity**			
Treatment	**Fungicide Rotation**	**8/18/2014**	**8/28/2014**	**9/7/2014**
1	Quintec only	0.0	0.3 A	2.6 A
2	Fontelis only	0.0	0.3 A	1.9 A
3	Procure only	0.0	0.2 A	2.3 A
4	Serenade only	0.0	0.2 A	2.1 A
5	Luna Sensation only	0.0	0.2 A	1.4 A
6	LunaS-S-LunaS-S-LunaS	0.0	0.2 A	2.0 A
7	Q-Q-F-F-F	0.0	0.4A	1.7 A
8	F-Q-Q-F-F	0.0	0.4 A	2.3 A
9	F-F-Q-Q-F	0.0	0.4 A	2.4 A
10	F-F-F-Q-Q	0.0	0.6 A	2.3 A
11	F-F-F-F-Q	0.0	0.5 A	2.2 A
12	F-F-F-F-F	0.1	1.3 B	1.8 A
13	Q-Pr-Q-Pr-Q	0.2	1.7 B	2.3 A
14	Untreated control	0.2	2.0 B	2.1 A

Table 15. Powdery mildew incidence and severity in fungicide mode-of-action studies in Central WA nurseries 2015.

2015

Treatment	Fungicide Rotation	6/27/2015		7/28/2015		8/14/2015	
1	Quintec only	0	A	54.255	AB	54.3	AB
2	Fontelis only	0	A	57.125	AB	57.1	A
3	Procure only	0	A	53.125	A	53.1	AB
4	Serenade only	0	A	53.87	AB	53.9	AB
5	LunaS only	0	A	48.5	B	48.5	B
6	LunaS-S-LunaS-S-LunaS	0	A	52.68	AB	52.7	AB
7	Q-Q-F-F-F	0	A	52.6	AB	52.6	AB
8	F-Q-Q-F-F	0	A	52.45	A	52.5	AB
9	F-F-Q-Q-F	0	A	52.55	AB	52.6	AB
10	F-F-F-Q-Q	0	A	54.425	AB	54.4	AB
11	F-F-F-F-Q	0	A	52.7	AB	52.7	AB
12	F-F-F-F-F	0	A	52.55	AB	52.6	AB
13	Q-Pr-Q-Pr-Q	0	A	54.74	AB	54.7	AB
14	Untreated control	0	A	52.87	AB	52.9	AB

Table 16. Powdery mildew incidence and severity in fungicide mode-of-action studies in Central WA nurseries 2016.

2016	**Powdery Mildew Disease Severity**								
Treatment	**Fungicide Rotation**	**8/8/2016**		**8/22/2016**		**8/31/2016**		**9/19/2016**	
1	Q-Q-Q-Q-Q	0.17	A	3.73	BCD	4.12	ABC	47.6	BCDE
2	Gem-Gem-Gem-Gem-Gem	0.07	A	1.89	CD	1.66	C	44.905	CDEF
3	Pr-Pr-Pr-Pr-Pr	0.19	A	2.61	BCD	4.785	ABC	56.64	A
4	LunaP-LunaP-LunaP-LunaP-LunaP	0.3	A	3.365	BCD	6.125	AB	53.68	BC
5	LunaS-LunaS-LunaS-LunaS-LunaS	0.01	A	1.23	D	3.045	BC	40.25	EF
6	LunaS-S-LunaS-S-LunaS	0.18	A	4.795	B	4.81625	ABC	56.48	AB
7	Q-Q-F-F-F	0.175	A	3.725	BCD	4.58	ABC	46.3	CDEF
8	F-Q-Q-F-F	0.1	A	4.355	BC	3.4425	BC	50.55	ABCD
9	F-F-Q-Q-F	0.12	A	3.5	BCD	2.995	BC	38.575	F
10	F-F-F-Q-Q	0.09	A	3.075	BCD	3.6	BC	52.8	ABC
11	F-F-F-F-Q	0.03	A	2.235	BCD	5.09	B	48.135	ABCDE
12	F-F-F-F-F	0.115	A	2.8	BCD	7.2	A	50.05	ABCD
13	Q-Pr-Q-Pr-Q	0.16	A	3.415	BCD	4.47	ABC	45.875	CDEF
14	Untreated control	0.09	A	7.6425	A	7.35	A	42.375	DEF

Table 17. Effect of fungicide program on chasmothecia production and ascospore viability in Central WA nurseries 2015 and 2016.

2015					
Treatment	Fungicide Rotation	Avg. Number of Chasmothecia		Ascospore Viability (%)	
1	Quintec only	1068.7	ABC	16.5	AB
2	Fontelis only	N/A		N/A	
3	Procure only	N/A		N/A	
4	Serenade only	1149.35	AB	18.25	AB

5	Luna Sensation only	295.2	C	10.25	B
6	LunaS-S-LunaS-S-LunaS	445.85	BC	10.75	AB
7	Q-Q-F-F-F	824.7	ABC	23	AB
8	F-Q-Q-F-F	951.2	ABC	13.5	AB
9	F-F-Q-Q-F	981	ABC	18	AB
10	F-F-F-Q-Q	1071.4	ABC	18.5	AB
11	F-F-F-F-Q	830.75	ABC	15.25	AB
12	F-F-F-F-F	877.15	ABC	19	AB
13	Q-Pr-Q-Pr-Q	1151.55	AB	17.75	AB
14	Untreated control	1427.95	B	26.25	A

2016					
Treatment	Fungicide Rotation	Avg. Number of Chasmothecia		Ascospore Viability (%)	
1	Quintec only	11.8	AB	4.6	A
2	Gem only	9.3	B	1.7	A
3	Procure only	71.0	AB	5.6	A
4	Luna Privilege only	25.0	AB	6.8	A
5	Luna Sensation only	7.8	B	5.8	A
6	LunaS-Serenade -LunaS-Serenade-LunaS	131.8	A	9.0	A
7	Q-Q-F-F-F	29.0	AB	7.9	A
8	F-Q-Q-F-F	63.3	AB	6.8	A
9	F-F-Q-Q-F	27.8	AB	4.5	A
10	F-F-F-Q-Q	36.3	AB	7.9	A
11	F-F-F-F-Q	22.8	AB	3.1	A
12	F-F-F-F-F	42.5	AB	4.5	A
13	Q-Luna Privlege-Q-Luna Privlege-Q	29.0	AB	2.8	A
14	Untreated control	92.8	AB	8.0	A

Table 18. Effect of Bacillus subtilis (Serenade), Bacillus pumilis (sonata), EO water, plant activator (Actigard) and SDHI on chasmothecia number in Quincy nursery 2015
1Sprays were applied at 14-day intervals beginning at the first signs of powdery mildew
2 Number of chasmothecia obtained from 1 gram of ground leaf tissue
3Means followed by the same letter are not significantly different according to GLM procedure LSD test at p<0.05

Treatment[1]	**Chasmothecia Number**[2]	**% Chasmothecia viable**
EO water	210b[3]	4.5c
Serenade	1149ab	18.25ab
Luna sensation	446b	10.75bc
Actigard	3789a	16abc
Sonata	1106 ab	24.25a
Luna sensation +Serenade	459b	10.25bc
Untreated	1428ab	28.25a

Objective 4 Approach and Results (Tables 19-22). Identification of critical spray timings for interruption of chasmothecia formation by quinoxyfen applications applied 100 through 1200 growing degree days after the first observance of powdery mildew signs. Fontelis (penthiopyrad) was applied at all other times in the spray regimes. *The timing of application of quinoxyfen did not significantly affect chasmothecia formation in 2015 and 2016 (Tables 21 and 22). Applications at 1200 cumulative degree days significantly reduced chasmothecia numbers in 2014 (Table 20).*

Table 19. Fungicide application schedule (moving quinoxyfen application). GDD = degree day thresholds (base 50) following identification of initial symptoms.

TMT #	First symptoms	100GGD	200GGD>	400 GGD	800 GGD	1200 GGD
15	Quintec	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis
16	Fontelis	Quintec	Fontelis	Fontelis	Fontelis	Fontelis
17	Fontelis	Fontelis	Quintec	Fontelis	Fontelis	Fontelis
18	Fontelis	Fontelis	Fontelis	Quintec	Fontelis	Fontelis
19	Fontelis	Fontelis	Fontelis	Fontelis	Quintec	Fontelis
20	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis	Quintec
21	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis
22	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis	Fontelis
23	Untreated	Untreated	Untreated	Untreated	Untreated	Untreated

Table 20. Effect of quinoxyfen application timing on chasmothecia production and ascospore viability in Central Washington nurseries, 2014. The initial quinoxyfen applications were made according to various cumulative degree day thresholds (base 50) between 100 and 1600 (after the initial appearance of powdery mildew signs).

Timing of Initial Quinoxyfen Application	Chasmothecia Production
Initial signs of powdery mildew	591.2 AB
100 CDD[1] > 50 F	594.5 AB
200 CDD > 50 F	826.2 A
400 CDD > 50 F	549.2 B
1200 CDD > 50 F	731 A
1600 CDD > 50 F	564.5 B
None (penthiopyrad only)	546 B
Untreated	600.8 A

[1] = cumulative degree days (base 50 F) from initial observance of symptoms.

Table 21. Effect of quinoxyfen application timing on chasmothecia production and ascospore viability in Central Washington nurseries, 2015.

2015					
Treatment	Fungicide Rotation	Avg. Number of Chasmothecia		Ascospore Viability (%)	
15	Q-F-F-F-F-F-F	1052.3	A	18.3	A
16	F-Q-F-F-F-F-F	1536.2	A	22.5	A
17	F-F-Q-F-F-F-F	1494.8	A	16.3	A
18	F-F-F-Q-F-F-F	1324.7	A	18.8	A
19	F-F-F-F-Q-F-F	1335.3	A	18.0	A
20	F-F-F-F-F-Q-F	1602.8	A	17.0	A

21	F-F-F-F-F-F-Q	1342.6	A	25.0	A
22	F-F-F-F-F-F-F	1389.2	A	18.0	A
23	Untreated Control	1489.6	A	14.7	A

Table 22. Effect of quinoxyfen application timing on chasmothecia production and ascospore viability in Central Washington nurseries, 2016.

2016					
Treatment	Fungicide Rotation	Avg. Number of Chasmothecia	Ascospore Viability (%)		
15	Q-F-F-F-F-F-F	11.8	A	3.4	A
16	F-Q-F-F-F-F-F	23.0	A	2.2	A
17	F-F-Q-F-F-F-F	10.5	A	2.5	A
18	F-F-F-Q-F-F-F	12.5	A	4.2	A
19	F-F-F-F-Q-F-F	38.0	A	3.8	A
20	F-F-F-F-F-Q-F	36.3	A	7.2	A
21	F-F-F-F-F-F-Q	29.0	A	4.3	A
22	F-F-F-F-F-F-F	21.5	A	2.4	A
23	Untreated Control	28.8	A	3.4	A

Van Well Nursery provided multiple plot locations during all years of the study. Nursery personnel conducted all IPM (other than fungicide applications) and horticultural support in the multiple plots. A total of 6 plot years were provided. Each plot was about 0.5 acre in area.

Tree Fruit Research and Extension Center. TFREC provided laboratory space connected with the insect aspects of the study.

Washington Tree Fruit Research Commission. Provided matching support for the project via projects "Factors Affecting the Fruit Phase of Powdery Mildew of Cherry".

Oregon Sweet Cherry Commission. Provided matching support for the project via projects "Factors Affecting the Fruit Phase of Powdery Mildew of Cherry".

JMS Flower Farms. Donated JMS Stylet oil for all aspects of the project.

Wilbur-Ellis Incorporated. Wilbur-Ellis assisted with the identification of commercial study orchards in Wenatchee and Pasco. Wilbur-Ellis personnel and associates assisted with fungicide applications during years 1 and 2 of the study.

Hayden Farms. Provided land, equipment, and labor and applied treatments to large multiple acreage plots during all years of the study. This aspect of the project focused on application of horticultural oils after harvest. Chasmothecia and mite data were collected by project personnel during all years of the study.

This project did not benefit non-specialty crops.

GOALS AND OUTCOMES ACHIEVED

The primary outcome of this project was to demonstrate to the cherry industry that management of powdery mildew requires the management of two separate but related epidemics: management of the disease on fruit to ensure farm gate in any given year, and management of the foliar phase to reduce disease pressure in the following and subsequent year(s). Measurable outcomes included evolution in powdery mildew management practices and a framework for overall improvement in fungicide resistance management approaches (through deployment of specific fungicide modes of action at key epidemiological times). A significant outcome was the demonstration that the use of narrow range petroleum oils did not disrupt or aggravate the overall IPM (e.g. mites) system.

Goal(s): Evaluation of timings of various fungicide modes of action for disruption of chasmothecia formation. Various phenological or weather based applications of quinoxyfen did not reveal a critical spray timing. The effects of applying the initial quinoxyfen spray according to various degree day thresholds (following the initial appearance of symptoms) were insignificant.

Goal: Determine the effect of various fungicide modes-of action on chasmothecia production. Only Luna Sensation (fluopyram + trifoloxystrobin) and Gem (trifloxystrobin) significantly reduced chasmothecia studies. Luna Privilege (fluopyram) did not, indicating that activity was due to the trifloxystrobin components. However four applications were needed, more than FRAC guidelines for managing resistance to QoI compounds. Alternations of QoI + biologicals (Serenade) did not inhibit chasmothecia formation.

The industry-wide change in management approaches is a long-term endeavor. Results of this project provided knowledge on the effectiveness of QoI fungicides for reducing chasmothecia formation, the relative ineffectiveness of full season programs (standard preharvest + postharvest oil applications) on the potential reduction of overwintering inoculum, and the potential disruption of the overall IPM system (mites) by those full season programs. The project demonstrated that some fungicide modes of action (e.g. QoI) were more effective in preventing chasmothecia formation than others but their adoption in orchards for use in this matter would be counter to current resistance management strategies. However, a positive outcome of the studies was that postharvest oil applications did not increase applications of deleterious mites.

Proposed Activity	**Accomplished Activity**	**Comments**
Industry survey	Survey complete 10/14	Poor survey response
Fungicide mode of action studies	Trials conducted 2014-2016	QoI and electrolyzed water class were identified as efficacious in reducing chasmothecia populations.
Fungicide timing studies	Trials conducted 2014-2016	Various timings of quinoxyfen applications in calendar and weather-driven programs were demonstrated as ineffective in reducing chasmothecia numbers.
Evaluation of full season synthetic/oil programs in reducing chasmothecia numbers	Trials conducted 2014-2016	Full season programs were inconsistent in reducing chasmothecia numbers but did not aggravate mite problems or disrupt the overall IPM system.
Economic analyses	End of project	Costs of full-season programs that conformed to FRAC guidelines were compared; non-compliant programs were considered unsustainable.

Survey results revealed a marginal understanding of disease biology and a potential conflict of interest vis a vis disease recommendations. The results of the experiments were encouraging in some respects but inconsistent in others. For example, experimental differences evident in experimental versus commercial orchards, and differences between lower and upper tree canopies, indicate that various application technologies should be evaluated. Furthermore, the performance of some key synthetic fungicides was mediocre in experimental orchard studies; a resistance survey is warranted. Efficacy data has been shared with industry. Positive results include the identification of QoI and electrolyzed as potential candidates for inhibiting chasmothecia formation in subsequent studies.

BENEFICIARIES

The utility of QoI and oil fungicides for reducing chasmothecia populations were demonstrated in some of the nursery studies. Furthermore, contrary to popular opinion postharvest oil treatments in orchards did not result in additional challenges with mites. In addition, the efficacy of QoI and electrolyzed water fungicide classes was confirmed during the course of the study and some rotational combinations provided reductions in disease severity and chasmothecia production. Cherry growers in the Western US will benefit because of the increased understanding of various fungicide modes of action and the incorporation of “soft” products (e.g. oils and electrolyzed water).

Adoption of additional chemistries will improve disease and fungicide resistance management. QoI fungicides are critical components of preharvest programs and due to resistance concerns additional applications postharvest would not conform to resistance management guidelines. Petroleum oils have far lower resistance risk and are therefore the most logical additions to full season programs. However, oil performance in the orchard studies was inconsistent (significant reductions in chasmothecia numbers on 2014, insignificant in 2015-16).

Nursery programs that included 3 late season oil applications significantly reduced late season disease incidence and severity and chasmothecia numbers. Oil regimens (using a generic narrow-range petroleum oil) of this sort would increase disease management costs from $200 to $224 per acre per season. The ability of such regimens to delay disease onset in orchards in spring needs to be demonstrated before the approach should be adopted as an industry-wide practice.

Chasmothecia numbers were not reduced by full-season orchard programs that conformed to resistance management guidelines. Furthermore, the inclusion of oils in such programs increased disease management costs from $200 to $224 per acre per season. QoI compounds were effective in reducing chasmothecia but their utilization in full season programs would not conform to resistance management guidelines and would therefore risk product availability over time and increase disease management costs to > $300 per acre season.

LESSONS LEARNED

WSU had originally attempted to demonstrate delayed disease onset in commercial settings. The experience proved that much larger commercial plot sizes were required and that growers were hesitant to include untreated controls in plots. Therefore, the epidemiological conclusions, hoped to demonstrate will require a (at least 5 acre) research orchard planted on dwarfing roostocks. Dwarf trees would help to reduce the variability in spray coverage.

In nursery plantings the effect of spray interval on chasmothecia formation and disease severity was critical. For example, electrolyzed water (one of the most promising treatments) was effective when applied at 7 day intervals and ineffective if applied biweekly.

The efficacy of electrolyzed water and the QoI components of Luna Sensation and QoI Gem for reducing chasmothecia numbers was an unexpected but a positive outcome.

It was also discovered that more chasmothecia were produced in the upper (rather than lower) portions of tree canopies. Several factors may account for this including light penetration, spray coverage, and other environmental factors.

Narrow-range petroleum oils did not consistently reduce chasmothecia numbers when used as the postharvest component of full-season management programs in orchards. However, the oil applications did not result in significant increases in deleterious mites at either sites over the three-year study.

The purpose of this project was to develop an economically viable and sustainable approach to temporally extend the disease management window to minimize mid to late-season chasmothecia formation (= overwintering structures which can discharge ascospores in the spring) and as a result lower disease pressure over time. Reducing the amount of chasmothecia and the viability of ascospores should consequently lead to a reduction in primary inoculum in the spring. However, full season fungicide programs need to be appropriately designed in order to be economically feasible and in a fashion that will not put increased resistance selection pressure on essential synthetic fungicides. The interest in post-harvest disease control has increased steadily in the past years and this study addresses questions frequently asked by growers in both Washington and Oregon State. By contrasting different management approaches (e.g. extended fungicide sprays or post-harvest oil applications) efficacy of QoI and electrolyzed water fungicide and fungicide mixes to reduce chasmothecia production was demonstrated.

A thorough economic analysis of new program types was not completed due to the limited efficacy and biologically unsustainable nature of various programs.

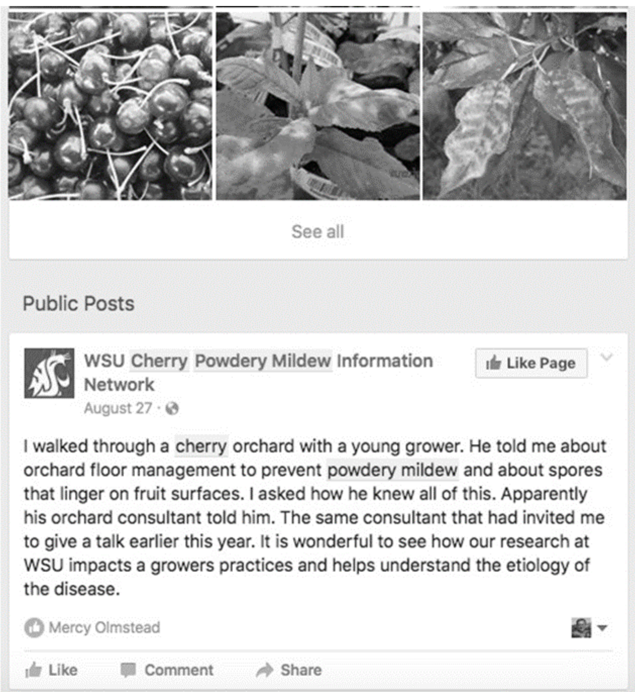
ADDITIONAL INFORMATION

Washington Tree Fruit Research and Oregon Sweet Cherry Commissions. These entities provided $191,415 for parallel studies under proposal "Factors Affecting the Fruit Phase of Cherry Mildew" and $140,000 for project "Podosphaera clandestina viability during post-harvest handling of sweet cherry fruit".

Van Well Nursery. Provided (in-kind) two, 1-acre plots during each year of the study and provided weed and insect control and water during the three years of the study.

Hayden Orchards. Provided (in-kind) 10 acre plots during all years of the study and covered all costs related to general horticulture and plant vigor, irrigation, insect management, and applied all postharvest fungicide applications.

A Facebook page on the disease was established in 2015 and will become the primary source of timely disease management information.



Publications:

Moparthi, S. 2016. *Epidemiology and Management of Powdery Mildew of Sweet Cherries in Washington Nurseries*. PhD Thesis, Washington State University.

Mildew threatens cherries all season. GoodFruit Grower Cherry Issue (Diseases) [February 15th 2015 Issue].

The problem of powdery mildew. GoodFruit Grower Cherry Issue (Diseases) [May 15th 2016 Issue].

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Project Title: Early maturing Dry Beans for Specialty Markets in Western Washington

Partner Organization: Washington State University (WSU)

PROJECT SUMMARY

For decades processing peas were a vital part of rotations in many western Washington counties. Today the industry and tens of thousands of acres of peas are gone. Farmers are looking for a legume to add to their rotations. Ideally this legume would require minimal, or no, processing and have value within local markets both economically and nutritionally. Dry beans fit this description very well. What is required to make them a success is identifying varieties that are early maturing, disease resistant and have excellent cooking and nutritional quality. This project's strategy is to utilize farmer knowledge to establish a collection of beans that have done well in western Washington to get a quick start on variety choice. This collection (which is at hand thanks to startup funding from the Port of Skagit and the Northwest Agricultural Research Foundation) will be combined with early maturing types that were sourced from germplasm collections and will be trialed in multiple locations so that recommendations can be made to growers on variety choice and planting date.

These needs are immediate. In 1990, 14,880 acres of peas were grown for processing in Skagit County alone (McMoran 2008), and today there are zero acres due to the loss of key processing facilities. The loss of peas is common up and down western WA, leaving a void in conventional and organic farming systems. Dry beans have the potential to fill a legume role in crop rotations, however, unlike processing peas, dry beans may be marketed directly to meet rapidly increasing demand for locally produced crops.

This project was not built on a previously funded SCBGP project.

PROJECT APPROACH

Dry bean germplasm was obtained from 5 public breeding programs: University of California, Davis (n=6); Michigan State University (n=12), North Dakota State University (n=9), Oregon State University (n=2); and USDA breeding program in Prosser, WA (n=11). Early maturing varieties were specifically requested from within major commodity market classes. In addition, commercially available varieties were purchased (n=18) and seed of locally grown heirloom varieties was obtained (n=5). In total 61 entries (2014) and 55 entries (2015 and 2016) were evaluated in the Skagit observational trial and 10 commercially available varieties were grown in the replicated yield trial (2014, 2015, and 2016).

Five growers were contacted and confirmed that they were willing to host on-farm trials in Skagit, Whatcom, Thurston, San Juan, and Island Counties. These sites represent diverse production systems and climates within western Washington.

Modifications were made to a custom built cone planter in order to mechanically seed trial plots and an appropriately sized combine sieve was ordered to enable direct mechanical harvest of plots.

Planned field trials were planted all three years with 2 replicates of 10 entries in 4 on-farm trials as well as 2 replicates of 60 entries in Skagit County. Planting dates ranged from May 14th to June 9th. Trials at WSU Mount Vernon were machine planted using a modified Allis Chalmers planting tractor in rows on 24 in centers. On-farm trials were hand planted to accommodate variation in row width and field size. Percent emergence was noted in all trials. Farmer-collaborators managed soil fertility, assisted with weed control, and provided irrigation at on-farm trials.

Notes on height and maturity range were taken on all trials. Further notes were taken on plant architecture and general appearance of the plants and pods. All field trials were harvested within a one month period. Trials were harvested sequentially to account for different maturities. Skagit County trials were harvested using a Wintersteiger plot combine. On-farm trials were harvested by hand and then threshed using the plot. Weed seed was cleaned from samples using a wind machine. Samples were weighed and yield was calculated based on plot size and estimated on a per acre basis.

Differences between the highest and lowest yielding lines amounted to several thousand lbs. per acre, which can translate immediately into thousands of dollars per acre. Differences in days to maturity between the earliest and latest maturing lines was as high as 34 days, which is significant for western WA where there are frequently early fall rains that can prevent a successful harvest. Project members are not comfortable making direct varietal recommendations, but instead present results from all trials for farmers to read and determine which varieties will perform best in their system. Preliminary data for the yield trial and observation trial are available at the end of this report in the Additional Information section.

Dr. Stephen Jones, director of the Bread Lab and professor at WSU-NWREC oversaw the project. Jeanne Burritt, the administrative manager at WSU-NWREC oversaw the budget. Dr. Brook Brouwer collected germplasm, developed the experimental design, and planted and maintained the first year of the trial for his PhD project. Brigid Meints conducted the experiments in the second and third year, and performed all data collection and analysis as part of her PhD project. Farmers in Skagit, San Juan, Island, Thurston, Whatcom, and Jefferson Counties allowed the use of their land for the trials.

This project does not benefit non-specialty crops.

GOALS AND OUTCOMES ACHIEVED

In May of each year, yield trials and observational trials were planted in multiple counties in western WA. The yield trials consisted of 10 commercially available varieties from several market classes in a randomized complete block design with two replicates at four or five counties (Skagit, Whatcom, Island, San Juan, Thurston, and Jefferson). The observational trial consisted of 55-61 lines (heirlooms, commercially available varieties, and breeding lines) planted in a randomized complete block design with two replicates in Skagit County. During the growing season, notes were taken on percent emergence, days to maturity, plant height, general appearance, and whether disease pressure was present. Lodging and amount of defoliation prior to harvest were also measured in 2016. The Skagit County trials were harvested directly using a combine. Trials in other counties were harvested by hand into gunny sacks and threshed using the same combine. After harvest was completed, yield, moisture, hundred bean weight, and the percentage of split and moldy beans was measured. Samples were sent to other labs for mineral and phytic acid analysis. These trials were the heart of this project and the valuable notes that were recorded on each line will serve to inform farmers on the quality of early-maturing varieties.

As a result of this project, an expected long term outcome was to increase the acreage of dry beans in productions in western Washington. However, as this is difficult to measure, it was not strictly quantified.

Each year, dry bean variety trial data was posted to the Bread Lab website (http://thebreadlab.wsu.edu/western-washington-variety-trials/) and shared with growers at annual field days in order to make progress towards this outcome.

The main goal of this project was to identify early maturing dry bean varieties suitable for direct marketing in western WA resulting in increased production. In order to accomplish this, activities included germplasm collection and field trials in five counties in western WA, with evaluation of agronomic and quality traits. This goal was successfully accomplished through the field trials and post-harvest analysis.

A survey of farms in western WA conducted in 2013 to collect information on bean types grown in the past 100 years that perform well in cool maritime climates, had over 90 respondents from 14 counties who indicated that they were currently growing or interested in growing dry beans. However, because of a lack of regional variety testing for dry beans, growers are at a loss when it comes to varietal choice. Choice of variety can affect yield, which can affect profit. This trial introduced a regional variety testing project over a number of representative counties in western WA in order to provide growers with an idea of which varieties or heirlooms perform best in their region. These data are published and available for anyone to view. A survey is currently ongoing to provide quantitative data on the number of growers who found this research useful.

BENEFICIARIES

The farmers who hosted the on-farm trials gained the greatest benefit from this trial. All farms included in this trial are practicing, or certified, organic. Because organic farming practices are so diverse, on-farm trials are the best way to determine which varieties will be most successful at that spot. Therefore, the farmers who hosted trials can look at the data and learn which varieties performed best on their farm. However, this project can benefit anyone interested in growing dry beans at any scale of production in western WA. The counties that hosted the trials ranged from the South Sound to the North Sound to the Islands, allowing farmers to extrapolate the results to their area based on whichever trial spot is most similar.

The quantitative results from this trial are summarized in the "Additional Information section" below. Differences between the highest and lowest yielding lines amounted to several thousand lbs. per acre, which can translate immediately into thousands of dollars per acre. Differences in days to maturity between the earliest and latest maturing lines was as high as 34 days, which is significant for western WA where there are frequently early fall rains that can prevent a successful harvest. Project members are not comfortable making direct varietal recommendations, but instead present results from all trials for farmers to read and determine which varieties will perform best in their system.

LESSONS LEARNED

Upon completion of the multi-county dry bean trials, project members were struck by the yield potential of dry beans in western WA. Although a maritime climate may not be the ideal location for growing dry beans due to cooler temperatures and early fall rains, the yields were comparable to dry beans grown in central WA, including the target early-maturing varieties.

In discussions with farmers about dry beans, project members realized that varietal choice is not the only issue holding back production. Many smaller farmers were interested in scaling up their production, but lacked appropriate infrastructure, including harvest and threshing equipment and drying facilities. These farmers are currently harvesting beans by hand and using primitive threshing methods that are not efficient for their system. While this research will provide useful varietal information, there remains a bottleneck for many farmers to increase production that will need to be solved before beans can become a widely grown crop in western WA.

Project members feel that despite some setbacks, this project was very successful in meeting the goal of identifying early-maturing varieties for western WA and are eager to begin using this information to begin breeding new varieties of dry beans.

Although dry beans are a primarily self-pollinating crop, there was a small percent of outcrossing between plots. These off-types were planted out and allowed to segregate. The next logical step in this project is to begin breeding new varieties of beans using early maturing types as parents in order to get other traits (disease resistance, seed coat color and pattern, growth habit, etc.) into an early maturing background to create more options for farmers in the future. With the outcrossing that occurred, the program was able to get a jumpstart on the breeding process when one of the parents of the off-types was identified as one of the early maturing heirlooms.

Another unexpected outcome was getting one of the beans trialed into a fine-dining restaurant in Seattle. One of the farmer partners began experimenting growing a few of the varieties on an acre each. The restaurant 'Canlis' is purchasing beans for their menu from this farmer. The bean dish was mentioned in a write-up by the Seattle Times: http://www.seattletimes.com/life/food-drink/timeless-yet-relevant-canlis-is-superb-under-new-chef/.

Each year of the project, project members had issues working with some of the farmer-collaborators. There were problems with on-farm management and poor communication that resulted in the loss of trials at some locations. Because of this, there are only results from 4 counties in year one and 3 counties in year two and three. On the other hand, several of the farmers were very easy to work with because they were invested in the research and supporting graduate students. Project members learned that for on-farm research it is very important to find farmers who are willing to work with researchers and understand the nature of research trials. Creating a bond between researcher and farmer was key to a successful trial. Another issue that came up when trying to complete the outlined activities was the timeline of the granting agency compared with the dry bean production timeline. The grant ended on September 29th, 2016. This project involved three growing seasons with post-harvest analysis in all three years. However, the final bean harvest was not completed until October 4th, 2016. Therefore, threshing, processing, and especially quality analysis were delayed until after the granting period ended. Because of this, the project members made the decision to postpone the final survey until after the year three data could be posted because they were not comfortable making variety recommendations until all data were available. This survey is now underway. Therefore, although the goal was met, the performance measure of how many farmers found the results useful has not yet been quantified.

ADDITIONAL INFORMATION

There were no cash donations contributed to this project. For In-Kind matches, WSU included in the proposal the following information on other resources available which are in support of similar research/activities undertaken by the Principal Investigator (PI). These resources are listed to identify other support for this research and are not included as a commitment of cost share by WSU. Unrecovered F&A from the PI's involvement is valued: Yr. 1—14,304, Yr. 2 – 14,725, Yr. 3 – 15,171.

Dry Bean Yield Trial across 4 counties in Western WA, 2014

Variety Name	Market Class	Yield (lb/A)	Clean yield (lb/A)	Plant height (cm)	Maturity rating (1-3)*	Emergence (%)	Hundred bean weight (g)
Island County							
Black coco	Black	612	587	32.5	1.0	80.6	53.8
CELRK	Kidney	808	805	37.5	2.0	76.4	59.6
Eclipse	Black	1493	1462	39.0	3.0	84.7	21.6
Etna	Cranberry	1600	1387	28.5	1.0	66.7	53.5
King of the early	Cranberry	1471	1399	38.5	1.0	83.3	60.2
Orca	Black and White	575	543	30.0	3.0	19.4	32.7
Silver cloud	White Kidney	629	569	41.5	3.0	55.6	57.2
Bright stone	Cranberry	1457	1421	32.0	1.5	80.6	41.2
Rockwell	Red and White	1396	1352	35.0	1.0	63.9	45.7
Whipple	Cranberry	929	881	31.5	2.0	59.7	68.3
CV %		61.1	58.3	13.0	12.1	11.8	12.3
LSD (P=0.05)		1539	1373	10.2	0.5	17.7	13.7
Mean		1097	1040	34.7	1.9	66.7	49.4
Minimum		575	543	28.5	1.0	19.4	21.6
Maximum		1600	1462	41.5	3.0	84.7	68.3
San Juan County							
Black coco	Black	610	571	35.6	2.0	75.0	48.7
CELRK	Kidney	1270	1237	37.5	1.0	86.8	57.2
Eclipse	Black	53	52	36.2	3.0	81.9	16.9
Etna	Cranberry	1338	1043	37.5	1.0	84.0	46.9
King of the early	Cranberry	1149	1080	36.2	1.0	87.5	52.7
Orca	Black and White	29	26	36.8	3.0	89.6	33.0
Silver cloud	White Kidney	414	280	34.3	3.0	77.8	63.2
Francis kring	Cranberry	1158	1108	33.7	1.0	93.1	52.8
CV %		43.8	39.7	9.6	0.0	7.1	3.4
LSD (P=0.05)		777	634	8.2	0.0	14.2	3.7
Mean		750	675	36.0	1.9	84.5	46.9
Minimum		29	26	33.7	1.0	75.0	16.9
Maximum		1338	1237	37.5	3.0	93.1	63.2
Skagit County							
Black coco	Black	369	336	26.6	1.0	45.0	53.6
CELRK	Kidney	440	419	27.1	1.0	50.0	53.3
Eclipse	Black	991	985	31.6	2.0	87.5	22.1
Etna	Cranberry	961	877	26.9	1.0	77.5	57.3
King of the early	Cranberry	594	561	29.0	1.0	85.0	52.1
Orca	Black and White	340	273	36.3	3.0	12.8	32.8
Silver cloud	White Kidney	680	666	38.9	2.0	42.5	60.0
Rojo chiquito	Small Red	1237	1222	40.8	2.0	72.5	22.9
CV %		46.8	50.7	14.3	0.0	22.6	3.5
LSD (P=0.05)		503	497	6.8	0.0	19.6	2.2
Mean		702	667	32.1	1.6	59.1	44.0
Minimum		340	273	26.6	1.0	12.8	22.1
Maximum		1237	1222	40.8	3.0	87.5	60.0
Thurston County							
Black coco	Black	3541	2687	53.5	1.0	78.5	58.9
CELRK	Kidney	4240	3759	58.5	1.0	91.0	64.8
Eclipse	Black	4123	3620	67.0	3.0	91.0	20.8
Etna	Cranberry	4419	2702	56.5	1.0	77.1	62.7
King of the early	Cranberry	4532	3861	59.5	1.0	91.7	62.9
Orca	Black and White	4857	4354	59.0	2.0	73.6	35.1
Silver cloud	White Kidney	4875	4299	70.5	2.0	92.4	74.4
Calypso	Black and White	3714	2964	54.5	1.0	87.5	55.5
CV %		32.2	37.3	10.1	0.0	7.9	5.7
LSD (P=0.05)		3263	3118	14.3	0.0	15.9	7.3
Mean		4288	3530	59.9	1.5	85.3	54.5
Minimum		3541	2687	53.5	1.0	73.6	20.8
Maximum		4875	4354	70.5	3.0	92.4	64.8

Dry Bean Yield Trial across 3 counties in Western WA, 2015

	Emergence (%)	Split (%)	Moldy (%)	Hundred Bean Weight (g)	Maturity (1-3 rating)	Height (in)	Moisture at harvest (%)	Yield (lb/A)
San Juan County								
Desert Song	25	34	11	26	2	13	20.8	318
Eclipse	45	15	9	15	2.5	13	32.6	240
Etna	50	32	16	48	2	11	35.0	253
Island	40	20	2	28	1	11	18.1	212
LRK	60	16	13	57	2.5	13	29.2	103
Orca	45	14	9	26	2	13	24.4	164
Rockwell	35	18	6	38	1.5	12	29.4	165
Rojo Chiquito	60	7	18	17	2	11	35.0	208
Sedona	30	27	6	27	2	12	26.2	203
King of the Early	50	21	18	51	2	14	35.0	125
CV (%)	**21.7**	**20.4**	**22.3**	**4.7**	**31.8**	**15.7**	**15.2**	**23.9**
LSD (p = 0.05)	**22**	**--**	**--**	**--**	**1.4**	**4**	**9.8**	**108**
Mean	**45**	**21**	**10**	**31**	**1.9**	**12**	**28.5**	**199**
Minimum	**25**	**7**	**2**	**15**	**1**	**11**	**18.1**	**52**
Maximum	**60**	**34**	**18**	**57**	**2.5**	**14**	**35.0**	**329**
Skagit County								
Desert Song	90	16	3	31	2	20	24.2	3644
Eclipse	93	2	2	21	3	21	24.6	3458
Etna	88	34	7	55	2	14	23.3	1963
Island	93	8	1	44	1	32	22.0	3218
LRK	90	23	3	60	1	16	21.2	2768
Orca	88	2	10	31	3	17	26.4	2142
Rockwell	95	12	2	49	1	16	21.0	2063
Rojo Chiquito	93	1	9	22	2.5	27	29.4	1965
Sedona	93	11	12	36	3	24	26.4	2555
King of the Early	90	11	6	54	1	16	24.2	3056
CV (%)	**4.8**	**30.8**	**97.6**	**4.5**	**11.5**	**19.9**	**13.9**	**28.2**
LSD (p = 0.05)	**10**	**9**	**12**	**4**	**0.5**	**9**	**7.6**	**1590**
Mean	**91**	**12**	**6**	**40**	**1.9**	**20**	**24.3**	**2469**
Minimum	**88**	**1**	**1**	**21**	**1**	**14**	**21.0**	**1083**
Maximum	**95**	**34**	**12**	**60**	**3**	**32**	**29.4**	**4358**
Thurston County								
Desert Song	90	28	13	33	1.5	20	22.6	3923
Eclipse	90	16	1	24	2	30	20.3	4466
Etna	93	63	5	69	3	16	16.6	4472
Island	90	23	16	43	1	35	22.6	4313
LRK	88	80	1	63	1.5	20	14.6	3149
Orca	85	5	31	37	3	32	35.0	3816
Rockwell	93	52	13	47	1	18	16.5	2948
Rojo Chiquito	98	4	6	24	2	27	27.5	4032
Sedona	95	49	2	40	3	34	17.6	3807
CV (%)	**5.4**	**34.9**	**80.9**	**7.1**	**15.6**	**7.3**	**18.9**	**17.2**
LSD (p = 0.05)	**11**	**29**	**18**	**7**	**0.7**	**4**	**9.4**	**1541**
Mean	**91**	**36**	**10**	**42**	**2**	**24**	**21.5**	**3890**
Minimum	**85**	**4**	**1**	**24**	**1**	**16**	**14.6**	**2204**
Maximum	**98**	**80**	**31**	**69**	**3**	**35**	**35.0**	**4890**

Dry Bean Yield Trial across 3 counties in Western WA, 2016

	Emergence (%)	Lodging (%)	Maturity (1-3 rating)	Height (in)	Moisture at harvest (%)	Yield (lb/A)	Split (%)	Moldy (%)	Hundred Bean Weight (g)
Jefferson County									
Desert Song	83	95	1.5	19	13	1454	37	2	22
Eclipse	88	13	3.0	20	14	802	13	1	16
Etna	90	60	1.5	19	16	1685	40	4	43
Island	83	75	1.0	31	14	1935	24	2	29
King of the Early	80	50	2.5	26	12	1338	46	6	47
LRK	68	58	1.5	25	14	1103	17	20	49
Orca	75	55	3.0	17	14	557	13	4	21
Rockwell	90	18	2.0	24	13	1123	32	1	38
Rojo Chiquito	60	28	2.5	20	15	617	9	2	17
Sedona	88	25	2.0	24	13	1371	37	3	25
CV (%)	**23.1**	**42.4**	**18.2**	**4.8**	**9.9**	**26.9**	**26.2**	**96.5**	**2.4**
LSD (p = 0.05)	**42**	**45**	**0.8**	**2**	**3**	**725**	**17**	**10**	**2**
Mean	**80**	**47**	**2.1**	**22**	**14**	**1182**	**27**	**4**	**31**
Minimum	**30**	**5**	**1.0**	**16**	**11**	**358**	**4**	**0**	**16**
Maximum	**95**	**95**	**3.0**	**32**	**17**	**2001**	**48**	**29**	**50**
Skagit County									
Desert Song	88	25	1.5	18	19	1180	4	1	33
Eclipse	90	18	3.0	23	20	2367	2	0	24
Etna	90	5	1.5	14	19	1680	7	1	60
Island	95	15	1.0	30	20	2260	1	1	40
King of the Early	80	10	1.0	18	20	1134	2	1	52
LRK	95	5	1.0	18	20	2586	2	0	58
Orca	80	25	3.0	18	19	1382	2	1	32
Rockwell	85	18	1.0	15	21	1901	2	1	45
Rojo Chiquito	90	8	3.0	22	20	3489	0	0	23
Sedona	95	20	2.5	23	18	3129	6	1	38
CV (%)	**6.0**	**47.6**	**18.5**	**7.7**	**2.6**	**21.9**	**85.8**	**97.2**	**3.4**
LSD (p = 0.05)	**12**	**15**	**0.8**	**3**	**1**	**1029**	**2**	**2**	**3**
Mean	**89**	**14**	**1.9**	**20**	**20**	**2081**	**3**	**1**	**41**
Minimum	**70**	**5**	**1.0**	**13**	**18**	**818**	**0**	**0**	**22**
Maximum	**95**	**30**	**3.0**	**32**	**22**	**4085**	**9**	**2**	**63**
Thurston County									
Desert Song	90	65	1.5	23	13	3042	34	2	31
Eclipse	93	48	2.5	25	11	1987	29	1	19
Etna	93	55	1.0	21	13	2304	42	1	48
Island	95	83	1.5	27	14	3406	9	2	40
King of the Early	88	63	1.5	18	14	1451	19	3	53
LRK	93	53	1.5	22	12	2042	32	3	55
Orca	88	65	3.0	19	10	1264	43	0	32
Rockwell	95	90	2.0	19	13	2328	37	2	47
Rojo Chiquito	95	48	2.5	20	15	2351	11	2	22
Sedona	93	70	2.0	29	13	3092	29	4	38
CV (%)	**3.1**	**47.2**	**38.4**	**13.2**	**9.9**	**37.1**	**33.3**	**76.5**	**7.0**
LSD (p = 0.05)	**7**	**68**	**1.7**	**7**	**3**	**1890**	**21**	**4**	**6**
Mean	**92**	**64**	**1.9**	**22**	**13**	**2297**	**28**	**2**	**38**
Minimum	**85**	**5**	**1.0**	**14**	**9**	**913**	**7**	**0**	**18**
Maximum	**95**	**90**	**3.0**	**30**	**16**	**4384**	**51**	**5**	**57**

Dry Bean Screening Trial at WSU-NWREC, 2014

Variety Name	Market Class	Yield (lb/A)	Clean yield (lb/A)	Days to maturity (days after planting)	Plant height (cm)	Hundred bean weight (g)	Emergence (%)
PK9-1	Pink	2410	2226	105	44	36.1	85
PK11-4-4	Pink	2131	2068	109	33	33.3	75
Stampede	Pinto	1938	1821	115	45	40.2	75
Rio Rojo	Small Red	1926	1863	112	36	29.5	80
Agate	Pinto	1893	1853	105	38	38.1	75
Rojo Chiquito	Small Red	1840	1823	117	43	22.4	75
Rosetta	Pink	1833	1514	125	49	37.3	60
Agassiz	Pinto	1740	1725	105	34	40.3	80
UCD9634	Pink	1725	1602	121	42	36.8	85
UI-239	Small Red	1696	1629	109	31	33.8	90
B12721	Black	1653	1613	117	32	24.0	80
SR10-2-4(1)	Small Red	1646	1594	112	35	37.7	50
Eclipse	Black	1537	1529	117	46	22.1	80
Othello	Pinto	1525	1499	105	36	39.5	70
Island	Pinto	1512	1485	105	40	42.4	80
Victor	Pink	1503	1475	105	29	35.4	75
UI-537	Pink	1470	1440	105	38	38.8	90
B12712	Black	1434	1257	121	40	21.8	85
PT12-31	Pinto	1386	1353	105	41	36.4	70
Sedona	Pink	1384	1211	117	46	41.2	75
C11266	Cranberry	1290	1210	105	31	48.0	75
Etna	Cranberry	1287	1177	105	32	59.4	70
FDM 9623	Flor de Mayo	1255	1239	105	35	39.1	75
BK11-8	Black	1252	1232	131	40	22.5	70
N12466	Navy	1243	1160	121	43	17.0	55
PT8-15	Pinto	1219	1136	105	33	42.0	85
B12724	Black	1213	1179	117	32	20.3	90
R11606	Flor de Mayo	1192	1162	117	39	31.6	85
Francis king	Cranberry	1150	1101	109	34	55.7	80
R11801	Flor de Mayo	1101	1049	105	34	33.5	85
Decker	Cranberry	1099	1071	112	35	74.3	25
CELRK	Light Red Kidney	1097	1055	105	29	54.2	75
King of the early	Cranberry	1073	1045	105	33	53.1	80
GN10-1-1	Great Northern	1013	971	117	31	38.8	6
ND061210	Dark Red Kidney	998	981	109	34	46.5	80
Matterhorn	Great Northern	985	930	117	38	38.6	15
Expresso	Black	979	940	105	24	21.2	50
N12467	Navy	977	934	121	37	17.8	45
ND061106	Light Red Kidney	951	907	112	36	48.7	65
N11277	Navy	930	899	121	37	19.4	15
Crimson	Cranberry	849	806	105	28	54.1	55
Youngquist brown	Brown	814	563	135	36	48.5	55
GN10-3-7	Great Northern	769	752	115	30	39.6	10
Rockwell	Red and White	764	742	105	29	44.7	55
Marfax	Brown	701	688	105	28	36.4	60
Indi	Navy	683	662	125	40	18.8	10
Kenearly	Colored patterned	673	651	109	32	46.0	15
Black coco	Black	672	636	105	29	50.5	25
Avalanche	Navy	661	644	137	37	21.7	30
Merlot	Small Red	635	615	137	35	34.9	50
Vermont Cranberry	Cranberry	626	589	121	29	64.5	50
Silver cloud	White Kidney	612	586	112	37	58.8	10
Red Hawk	Dark Red Kidney	573	556	105	31	46.8	35
UC White Kidney	White Kidney	501	456	121	45	50.4	6
Calypso	Black and White	491	452	105	29	48.1	45
Snowdon	White Kidney	469	454	109	29	59.3	6
Canario 707	Yellow	433	387	125	29	47.6	15
Orca	Black and White	303	250	125	35	33.6	11
CV %		23.6	23.8	2.5	11.1	2.8	20.6
LSD (P=0.05)		552	530	6	8	2.2	23
Mean		1366	1310	112	35	38.8	57
Minimum		303	250	105	24	17.0	6
Maximum		2410	2226	125	49	74.3	90

Dry Bean Observational Trial in Skagit County, 2015

	Emergence (%)	Maturity (1-3 rating)	Height (in)	Moisture at harvest (%)	Moldy (%)	Split (%)	Hundred Bean Weight (g)	Yield (lb/A)
Black								
B12712	85	1.0	18	20.9	0.9	1.8	18.5	1287
B12721	90	1.0	18	24.9	3.5	2.3	23.5	2237
B12724	85	1.0	16	20.6	0.4	4.8	17.4	1176
BK11-8	68	1.0	21	23.5	1.6	2.8	20.3	1093
Black coco	88	1.0	13	23.1	2.5	11.1	50.4	1448
Eclipse	73	1.0	22	23.2	1.4	1.4	20.6	1109
Expresso	95	1.0	15	21.9	0.8	5.2	21.7	1621
Zenith	85	1.0	20	16.8	0.1	26.9	19.2	1971
Black and White								
Calypso	90	1.5	13	23.7	2.2	14.1	51.4	1451
Orca	60	1.0	21	16.3	1.2	41.4	26.7	1056
Brown								
Marfax	85	1.0	15	23.6	0.7	10.3	37.7	1496
Cranberry								
C11266	90	1.0	14	22.2	0.2	14.8	47.1	1283
Etna	68	1.5	12	23.5	4.2	18.4	52.8	1093
King of the Early	90	1.0	14	21.7	1.3	11.8	53.3	1936
Krimson	90	1.5	18	23.7	5.8	22.8	55.8	1938
Vermont Cranberry	80	1.0	15	21.8	4.9	25.8	28.8	1857
Dark Red Kidney								
ND061106	90	1.0	18	31.0	10.4	3.3	48.2	1439
ND061210	95	1.0	18	23.3	2.8	4.5	46.1	2016
Red Hawk	80	1.0	19	24.7	2.2	2.5	47.3	1282
Flor de Junio								
Desert Song	85	1.0	24	21.6	1.1	8.1	29.6	2488
Flor de Mayo								
FDM9623	85	1.0	21	23.4	0.7	1.7	38.5	1764
Gypsy Rose	68	1.0	21	35.0	26.8	8.7	29.6	1331
Gold and white								
Jacob's Gold	80	1.0	14	19.5	0.4	87.5	50.0	1109
Light Red Kidney								
CELRK	90	1.0	14	22.3	2.6	9.2	57.3	2217
LRK	65	1.0	15	25.4	5.6	5.9	54.1	1125
Navy								
Moena	85	1.5	18	27.5	0.8	6.3	16.3	1728
Avalanche	85	1.5	23	23.4	3.3	1.8	21.4	1481
N13150	85	2.5	28	27.8	1.3	7.7	28.3	1512
N14150	95	1.5	20	18.0	1.2	5.9	15.6	1970
Pink								
PK11-4-4	90	1.0	18	22.0	0.8	2.2	30.9	1873
PK9-1	90	1.0	27	20.7	1.4	8.9	33.6	2531
Rosetta	90	3.0	24	17.5	0.7	49.7	27.6	1738
Sedona	85	1.0	20	26.7	9.5	5.8	34.7	1779
UCD9634	80	1.0	28	27.3	0.8	10.8	30.9	1866
UI-537	90	1.5	16	24.0	1.9	7.6	37.1	1191
Victor	90	1.0	17	24.6	2.7	2.2	33.8	1373
Pinto								
Agate	90	1.0	27	23.3	1.6	1.5	39.9	2667
Island	88	1.0	24	25.0	1.2	6.4	41.7	1180
Othello	68	1.5	18	24.9	2.2	4.6	37.5	1784
PT12-31	68	1.0	19	23.4	1.8	4.1	35.6	1676
PT8-15	88	1.0	28	29.9	1.1	17.7	41.6	1876
Quincy	80	1.0	23	27.9	0.7	15.3	48.3	858
Stampede	75	3.0	22	29.0	7.5	5.4	35.2	779
Red and White								
Jacob's Cattle	75	1.0	16	27.6	0.7	78.3	51.0	786
Rockwell	90	1.0	13	23.1	2.2	5.2	45.3	1281
Small Red								
Merlot	80	3.0	25	30.5	18.2	4.6	34.2	1527
R12844	88	3.0	18	28.1	0.5	36.7	29.3	976
Rio Rojo	60	2.0	22	26.9	8.5	3.7	32.4	825
Rojo Chiquito	80	1.0	22	21.2	4.3	9.9	19.9	1648
SR10-2-4(1)	90	3.0	24	26.7	11.7	2.1	37.4	1983
UI-239	65	3.0	28	25.0	2.3	1.5	32.3	2196
Yellow								
Canario 707	73	3.0	22	21.6	6.7	9.8	29.7	1465
DRY28-1	70	2.5	14	21.7	5.1	21.1	48.2	813
DRY60-1	85	3.0	21	27.2	8.2	3.9	43.4	1488
Yellow eye								
Kenearly	88	1.0	15	22.3	2.1	6.8	45.3	2233
CV (%)	18.4	20.6	15.8	8.7	77.8	40.0	15.5	35.1
LSD (p = 0.05)	18	0.7	6	4.0	5.5	11.3	8.3	1202
Mean	85	1.7	19	22.8	3.5	10.0	35.9	1536
Minimum	60	1.0	13	16.3	0.0	0.0	14.4	786
Maximum	95	3.0	27	35.0	32.9	88.0	58.4	3748

Dry Bean Observational Trial in Skagit County, 2016

	Emergence (%)	Lodging (%)	Defoliation (1-5 rating)	Maturity (d.a.p.)	Height (in)	Moisture at harvest (%)	Yield (lb/A)	Split (%)	Moldy (%)	Hundred Bean Weight (g)
Black										
BG2712	93	5	1	125	20	19	2888	3	1	21
BG2721	90	15	2	125	22	18	3009	5	0	25
BG2724	93	5	2	126	18	18	1794	5	2	22
BK11-8	90	18	2	125	23	19	2006	3	0	23
Black coco	95	8	4	114	18	17	1799	14	0	53
Eclipse	88	10	4	127	23	21	2767	2	2	23
Expresso	85	5	2	114	16	16	748	28	0	24
Zenith	90	5	3	125	21	26	2644	2	3	23
Black and White										
Calypso	75	10	4	114	16	17	591	18	0	53
Orca	60	10	4	135	16	22	683	3	2	54
Brown										
Marfax	88	5	4	114	14	17	1311	14	1	36
Cranberry										
C11358	88	8	4	114	14	17	1050	18	1	48
Etna	93	8	4	118	15	16	1269	19	1	58
King of the Early	75	10	4	114	18	18	1368	7	1	58
Krimson	73	20	3	116	17	16	925	18	0	56
Vermont Cranberry	90	35	3	125	28	20	1545	3	1	45
Dark Red Kidney										
ND061210	88	10	4	114	16	17	1280	4	1	67
Red Hawk	78	5	4	114	15	18	972	7	1	69
Flor de Junio										
Desert Song	93	10	2	116	19	17	1815	11	3	54
Flor de Mayo										
FDM0613	78	18	3	114	24	19	1827	8	0	38
Gypsy Rose	93	40	2	125	18	18	2437	3	2	33
Gold and white										
Jacob's Gold	83	5	4	114	13	17	774	17	2	55
Light Red Kidney										
CELRK	90	15	4	109	13	16	1236	12	1	61
ND061106	85	5	4	123	19	20	2252	2	3	47
Navy										
Alpena	85	10	2	125	20	20	1835	0	1	20
Avalanche	73	15	2	126	27	21	1205	0	2	22
N13131	90	5	2	135	25	20	2231	0	0	22
N14230	78	5	2	135	19	22	2321	0	2	20
Pink										
PK11-4-4	90	30	2	118	20	18	1982	1	0	32
PK9-1	90	20	2	116	23	19	1920	5	3	38
Rosetta	80	8	2	135	24	19	2739	2	3	40
Sedona	90	8	1	125	23	17	2498	7	2	38
UCD9634	93	8	4	130	20	20	2389	1	0	37
UI-537	75	35	3	114	29	17	864	4	1	39
Victor	83	70	4	116	27	17	1894	1	1	35
Pinto										
Agate	88	45	3	118	22	19	2864	1	2	41
Island	90	15	3	109	33	17	1857	6	0	41
Othello	75	15	2	114	24	18	687	7	1	40
PT12-31	88	10	3	116	20	18	1534	2	0	35
PT8-15	85	45	2	117	24	20	1486	7	5	43
Quincy	85	70	3	118	29	17	1890	6	0	44
Stampede	60	18	3	126	25	19	1965	4	1	48
Red and White										
Jacob's Cattle	83	5	4	109	14	17	1125	18	1	60
Rockwell	93	5	4	114	16	17	1339	18	1	67
Soldier	85	15	4	118	18	18	1571	5	2	64
Small Red										
Merlot	93	10	2	124	21	19	2873	0	1	26
R13544	93	5	1	118	13	18	1635	3	1	38
Rio Rojo	85	15	2	125	19	20	1182	1	1	38
Rojo Chiquito	90	5	3	123	20	19	3272	1	0	23
SR10-2-4(1)	85	10	2	123	24	18	2810	3	0	41
UI-239	88	38	4	116	18	19	956	1	3	33
Yellow										
Canario 707	53	8	4	137	15	25	576	1	7	68
OBY28-1	83	55	4	134	15	21	2268	1	3	45
OBY58-1	88	18	4	134	14	22	1464	1	3	46
Yellow-eye										
Kenearly	90	13	4	114	19	17	1938	12	0	46
CV (%)	**8.9**	**46.9**	**16.9**	**2.2**	**14.6**	**6.7**	**24.2**	**60.6**	**188.8**	**4.1**
LSD (p = 0.05)	**13**	**15**	**1**	**5**	**6**	**3**	**836**	**7**	**3**	**3**
Mean	**84**	**16**	**3**	**120**	**19**	**19**	**1680**	**6**	**1**	**39**
Minimum	**25**	**0**	**1**	**103**	**10**	**15**	**556**	**0**	**0**	**19**
Maximum	**95**	**70**	**4**	**137**	**35**	**27**	**3097**	**88**	**12**	**83**

CONTACT INFORMATION

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Project Title: Management of an Emerging Adelgid Pest on Nordmann Fir Christmas Trees

Partner Organization: Washington State University (WSU)

PROJECT SUMMARY

In 2010, an unidentified adelgid was detected on 5% of the Nordmann fir trees in a 2004 Christmas tree planting of approximately 750 Nordmann (Abies nordmanniana) and Turkish fir (Abies bornmuelleriana), located at the Washington State University (WSU) Research and Extension Center in Puyallup, WA. By 2012, 61% of the trees in this planting were badly infested and 16% were unmarketable. Large numbers of crawlers had attacked the foliage, which led to discoloration and severe distortion of the needles on affected shoots (Figure 1). The planting was part of a multi-site, Pacific Northwest (PNW) regional genetic trial designed to identify seed sources with superior postharvest needle retention. Dr. Gary Chastagner, WSU's Professor of Ornamental Plant Pathology who had established the PNW trial because of strong grower interest in these two Abies species, suspected that the damage was caused by the silver fir woolly adelgid [Adelges (Dreyfusia) nordmannianae], a serious pest in Europe where Nordmann fir is widely grown for Christmas trees, but not known to be present in the PNW. Unlike the balsam woolly adelgid (Adelges picea), which is established in the PNW and slowly builds up on susceptible Abies species, the silver fir adelgid is known to spread rapidly once it appears in European plantations.

Christmas trees represent approximately $42 million in farm income and WA is the fifth largest producer of cut trees in the US. Growers range from small, choose-and-cut farms to large wholesale operations. During the past 10 to 15 years there has been an increased interest in growing Nordmann and Turkish firs as Christmas trees in the PNW. Previous research has shown that these species have excellent postharvest moisture and needle retention when displayed in water and are tolerant or have limited susceptibility to Phytophthora root rot, Annosus root rot, spider mites, and balsam woolly adelgid. Since 2004, an average of 500,000 Nordmann/Turkish firs have been planted each year in Oregon. Although data are not available, a similar increase has taken place in western Washington and the Inland Empire. Currently, these species are the third most widely-planted Christmas trees in the PNW. Most of the Nordmann and Turkish fir have been planted in areas where noble fir cannot be grown because of Phytophthora root rot. The limited susceptibility of these species to common diseases and pests has also allowed growers to produce them with little or no applications of fungicides and insecticides.

In 2010, the WSDA SCBGP awarded WSU Puyallup a three-year grant to identify superior sources of Nordmann and Turkish fir. The goal of that project was to identify sources that are adapted to local production conditions and identify potential trees that have superior postharvest needle retention. It was while working on that 2010 project that the adelgid was detected on Nordmann and Turkish fir trees in the 2004 planting. The adelgid crawlers were attacking the foliage during the early stages of shoot elongation, causing discoloration and severe distortion of the needles on infested shoots. Although the identity and origin of the adelgid was unclear, Dr. Chastagner recognized that the damage to trees in Puyallup was very similar to what had been reported for silver fir woolly adelgid in Europe.

Several adelgids are serious pests of conifers in North America. One is the balsam woolly adelgid that has spread throughout North America and been responsible for the mortality of Fraser fir throughout its natural range. It is also a serious pest in areas where Fraser fir is grown as a Christmas tree, including the PNW. Another adelgid that attacks hemlock has become a serious problem in eastern North America. Adelgids have complex life cycles. In its natural range in the Caucasus region (Russia, Georgia, and Turkey), the silver fir woolly adelgid alternates between Oriental spruce (Picea orientalis), where the sexual stage occurs, and various Abies species such as Nordmann fir which host the asexual stage. In areas outside its natural range, it persists as an asexual population that reproduces parthenogenetically. Depending on temperatures during the growing season, there may be 2 to 6 generations of this pest, making control difficult (Figure 2). To complicate matters, the identification of a specific species of adelgid is based on the hosts on which they occur, morphological characteristics, and mitochondrial and nuclear DNA sequence data.

There are about 15 acres of Christmas tree research plots at Puyallup. The balsam woolly adelgid has been present in these plantings on a number of other Abies species, but most commonly on Fraser fir. Nordmann and Turkish firs have been grown here for almost 20 years with no previous adelgid problems. The newly-infested planting was located in an area that had previously only been used for forage production and close to residential areas, so the adelgid may have spread from infested landscape plants into the genetic planting. There is no indication that these pests can be carried on seed and all of the seedlings in this trial were grown from imported seed in a PNW nursery. Given the risk the unknown adelgid posed to plantings of Nordmann and Turkish fir that are being established in the PNW, Chastagner's lab at WSU Puyallup spent the past three years conducting studies to:

- Confirm the identity of the adelgid
- Determine the distribution of the adelgid in the PNW
- Determine the life cycle of the adelgid on Abies spp at WSU Puyallup
- Determine the growing degree days associated with emergence of the adelgid crawlers
- Determine the variation in susceptibility of commonly-grown Abies spp to the adelgid.
- Determine the effectiveness of commonly-available adelgid control products on Nordmann fir

In 2010, the WSDA SCBGP provided WSU Puyallup with a three-year grant to identify superior sources of Nordmann and Turkish fir. The goal of that project was to identify sources that are adapted to local production conditions and identify potential trees that had superior postharvest needle retention. The infestation of the trees in the 2004 Nordmann/Turkish fir genetic planting that was used in the 2010 project provided an unexpected opportunity to build on that by assessing the variation in resistance to the adelgids among the sources of Nordmann and Turkish fir.

PROJECT APPROACH

Activity. Sequence and use molecular markers to identify adelgid pest.

During spring 2013, various life stages of the adelgid were collected from Nordmann fir on the WSU Puyallup campus (Table 1). DNA was individually extracted from adults, eggs, and egg mass, and the cytochrome oxidase subunit I (COI) region of mitochondrial DNA was sequenced. The three samples sequenced were consistent with the Adelges piceae/nordmannianae/prelli group of adelgid species, a group within which species cannot currently be differentiated from each other by DNA sequence. In the summer and fall of 2013, additional samples were collected from a wider range of conifer hosts (Nordmann fir, Oriental spruce, spruce, and western hemlock (Tsuga heterophylla) in and nearby the WSU Puyallup campus (Table 1) to confirm that the adelgid on the Nordmann fir was unique compared to the adelgids on these other hosts. COI DNA analysis of the samples revealed a logical distribution of adelgid and host, and furthermore no adelgid from the Adelges nordmannianae and A. piceae complex were detected on any of the tested species other than Nordmann fir. The DNA sequences were aligned with sequences from known (voucher) adelgids in a phylogenetic tree (Figure 3), showing which adelgid species the WSU samples are most closely related to.

Dr. Nathan Havill at the USDA Forest Service Northern Research Station was contacted relating to issues associated with the molecular identification of the adelgid on Nordmann fir. Dr. Havill is an expert on adelgid identification and he indicated that the molecular technology is currently not available to distinguish between adelgids in the Adelges piceae/nordmannianae/prelli group. He indicated that within this group, host range is probably the most effective way of separating the species. Based on this, the results of the host susceptibility trials indicated that the adelgid is the silver fir woolly adelgid, [Adelges (Dreyfusia) nordmannianae].

Activity. Survey grower plantings of Nordmann and Turkish fir in WA and OR to determine distribution of adelgid pest.

The only locations where Chastagner's lab detected Nordmann fir infested with the adelgid were two sites located about 4 miles from the affected WSU Puyallup field plantings. His staff were unable to determine the source of both the infestations at WSU Puyallup and these sites. Following education and a request to growers at a regional Christmas tree meeting, samples were obtained from 25 growers in WA and OR. No evidence of adelgids was found on any of the samples. These data indicate that adelgids on Nordmann fir are either restricted to a relatively small number of sites in the Puyallup area or that common pest management treatments used by many growers in other areas are effectively controlling this pest.

Activity. Monitor changes in adelgid life stages on infested trees to obtain information on life cycle.

The silver fir woolly adelgid has a complex life cycle with the potential for multiple generations during each growing season (Figure 2). In addition, when it appears on Nordmann fir in Europe, it produces a winged form that colonizes Oriental spruce, the alternate host where the sexual stage of this pest occurs. Control treatments generally target the crawler stage, so it is important to understand when critical stages occur if growers are going to be able to effectively manage this pest. The life cycle of the adelgid was monitored on infested Nordmann fir trees at WSU Puyallup during 2013 through 2016. Branches were collected on a regular schedule and examined under a dissecting scope to determine the development of adelgid life stages throughout the year. All potential life stages of the adelgid that occur on their Abies host were observed on the Nordmann fir trees at Puyallup (Figure 4). There was a consistent progression through the life stages and there were two generations per growing season (Table 2). Overwintering stem mother's started laying eggs in late March. Egg hatch and 1st generation crawlers began to emerge in early April, about 1 week prior to initial bud break. The winged form was only evident on trees during 2013 and 2014.

Activity. Correlate growing degree data with emergence of crawler.
For each of the life stages observed, the growing degree days (GDD base 41) were calculated from March 1st using the following formula: GDD = (Max Daily Temp + Min Daily Temp)/2 – 41. The initial appearance of the 1st generation crawlers ranged from 217 to 380 GDD (avg. 285) over the 4 years (Table 2). Following bud break, which corresponded to 354 to 437 GDD (avg. 380), the crawlers moved onto and fed on the newly emerging growth. This indicates that growers could utilize GDD to optimize their adelgid control treatments.

Activity. Determine the risk that the adelgid could be spread via the movement of infested Christmas trees and boughs
Adelgids are known to be spread via wind, human activity, birds and infested seedlings. Little is known about the risk of spreading adelgids form one location to another via the movement of infested cut Christmas trees or boughs. As a result, controlled studies were conducted during the 2013-14 and 2014-15 harvest seasons to determine the risk that adelgids could be spread from one location to another via the movement of infested cut Christmas trees or boughs. Three sets of branches, consisting of a branch from each of five heavily-infested Nordmann fir trees, were harvested on December 5, 2013 and December 2, 2014, respectively. One set was stored in ventilated plastic crates outdoors. The other two sets were displayed indoors at 20C until early January; one set with their bases in water and the other dry. Following the indoor display period, both sets of branches were placed in ventilated plastic crates and stored outdoors with the others. A baseline check consisted of branches that remained on the infested source trees and were observed regularly. The effect of the different display and storage conditions on adelgid survival was determined by periodically examining the branches to determine the adelgid's viability and life stages through early April.

No evidence of overwintering stem mother (SM) adelgid mortality was evident on any of the detached branches in early January, except for a few branches that were displayed dry in the 2013-14 test. Unlike 2013-14, in the 2014-15 test none of the adelgids produced eggs on any of the indoor-displayed branches or when the branches were displayed outdoors (Table 3). This may have been due to differences in the environmental conditions that occurred prior to harvest in 2013-14 and 2014-15. Stem mother adelgids on the check branches that were not removed from the source trees began laying eggs about 3 weeks prior to bud break in late March, 2014 and 2015 March 26 and 30, respectively and the first crawlers were evident 19 days later (April 9 and 13, respectively). None of the SM adelgids survived on the branches that were stored outdoors or displayed in water and then stored outdoors long enough to lay eggs in the spring when new growth was appearing in the field. The data from these two trials indicated that there was no risk that the adelgids on Nordmann fir would spread via the movement of cut Christmas trees or boughs under the test conditions.

Activity. Variation in susceptibility of Nordmann, Turkish, Trojan and North American firs to adelgids.
Chastagner's lab utilized a number of existing genetic plantings at WSU Puyallup and a diverse set of Abies spp. seedlings to obtain information on the variation in susceptibility of different Abies spp. to the adelgid under PNW production conditions. Data were generally collected on the extent of needle curling and/or damage on each trees/seedlings. Curling was rated on a scale of 0 to 5, with 0 = no curling or evidence of adelgids, 1 = the tips of a few needles bent throughout the branches, 2 = some needles beginning to curl, with bent needles evident throughout the branch, 3 = almost all needles bent, many beginning to curl with slight yellowing, 4 = almost all needles curling with a yellow discoloration and damage easily visible from the top of the branch, and 5 = most needles curled throughout the branch and many are yellow or brown. Overall damage on each tree was rated on a scale of 0 to 3, with 0 indicating no damage and 3 indicating an unmarketable tree.

<u>2004 Nordmann/Turkish fir planting</u> - The adelgid damage was originally observed in 2010 in a 2004 replicated common garden planting at Puyallup of Nordmann and Turkish fir seed sources from Denmark and Turkey. The planting included 12 sources of Nordmann fir and 3 sources of Turkish fir. Ten trees from each source were planted in each of five blocks. After the original adelgid observation, changes in the level of damage were evaluated yearly from 2014 through 2016. In spring 2015, before the start of the growing season, approximately half of the trees were thinned out because of crowding in this plot. To determine if differences in severity of damage on different seed sources had stayed the same, the remaining trees were rated for adelgid damage at the end of the 2015 and 2016 growing seasons. The 2014 and 2015 ratings indicated that there were significant differences in susceptibility between sources of Nordmann fir, but only limited damage occurred on any of the Turkish fir (Table 4). The 2014 and 2015 data were subjected to Spearman Rank Order analysis to determine if relative susceptibility of sources was the same in both years. There was a highly significant correlation (P = 0.004) between the susceptibility rankings in 2014 and 2015. One of the most striking findings was the apparent natural collapse of the adelgid population and the limited damage that occurred on any of the trees in 2016 (Table 4). The reason is unclear, but additional studies might help to determine if this collapse was due to the buildup of natural predators.

2006 Republic of Georgia Nordmann fir planting – Another Nordmann fir field planting that was established in 2006 is located near the 2004 Nordmann/Turkish fir genetic trial plot. This plot consists of six different seed sources (numbered 33, 34, 35, 36, 37, and 38) from different elevations in the native range of the species in the Republic of Georgia. There are five trees from each source in each of 6 blocks (replications). Each tree was rated using the same damage scale described above. In 2014, 32% of the trees were affected, most with only a limited amount of damage. Analysis of the data showed no significant difference in the average damage to the different seed sources, which ranged from 0.23 to 0.56 within the plot. However, based on a visual representation of damage on the map that showed the spread of the adelgid within the plot, it appeared that the original infestation occurred in Rep 2 and was spreading through the other reps (Figure 5). During 2015, the number of trees (87.8%) and severity of adelgid damage increased (Figure 6). Even though the ratings were higher, analysis of the 2015 data, which ranged from 1.11 to 1.54, showed again that there was no significant difference in the average damage based on source (data not shown).

2014 Mixed *Abies* species trial - During 2013, 2014, and 2015, data were collected on the susceptibility of 13 different Abies species in a replicated, mixed demonstration planting located adjacent to the adelgid-infested 2004 Nordmann/Turkish fir genetic trial described above. In addition to adelgids that spread naturally from the adjacent 2004 planting, in spring 2013, small branches with overwintering adelgid stem mothers were harvested from infested trees and tied to a branch on each tree within this planting. The extent of needle curling and damage on each tree was then rated in the summer/fall of 2013, 2014, and 2015. Data in 2013 showed slight infestations on some species throughout the plot. Of the 13 species, the highest curling and damage ratings occurred on the Nordmann and European silver firs (Abies alba). Fraser (Abies fraseri), Canaan (Abies balsamea var. phanerolepis) balsam (Abies balsamea), Korean (Abies koreana), Nikko (Abies homolepis), and Turkish fir trees exhibited a very low level of curling at the site where the infested branch was secured to the tree in 2013 (Table 5). A year later, there was no evidence of adelgids on these trees, suggesting they were not able to overwinter and reproduce on any species in the planting other than the Nordmann and European silver firs (Table 5). Data in 2015 confirmed that collected in 2013 and 2014, with the exception of slight damage on Nikko and Turkish fir. Over the three year period, the highest level of damage occurred on the Nordmann and European silver firs. Since very little or no damage was observed on the other species, it would indicate that there is limited risk of this adelgid attacking species of Christmas trees grown in North America.

CoFirGE seedlings - The susceptibility of 1,420 seedlings from 71 sources, including Turkish fir, Trojan fir, and Nordmann fir that were obtained from a national CoFirGE project and representatives from other common North American Christmas tree species were evaluated for their susceptibility to adelgids in 2013 and 2014. In 2013, twenty seedlings of each species were placed in concrete bunkers underneath wire racks. Branches cut from infested Nordmann fir were placed on the racks to allow adelgid crawlers to fall onto the seedlings. A PVC hoop structure held shade cloth to protect the cut branches from direct sunlight (Figure 6). Branches were left for a two-week period and then replaced with fresh branches for another two weeks. A modified method was used to expose the same seedlings to adelgids in 2014. Instead of leaving branches above the seedlings on wire racks, infested branches were held above seedlings and clapped together. This was performed twice, on April 18th and April 30th. Sticky, 4 cm-square insect traps were placed among the seedlings to monitor the distribution of the adelgid crawlers that fell onto the seedlings during both years. In 2013, the average total number of crawlers captured on each 4 cm-square trap was 115 (23 crawlers per 0.8 cm squared), but there was a very uneven distribution throughout the different reps in the experiment (Figure 7). Results from the 2014 insect traps show that the modified method of infesting the seedlings was a less effective method. Though large numbers of eggs were found on the traps, the numbers of crawlers was much lower than in 2013 (Figure 8). The average total number of crawlers captured on each 4 cm-square trap was 20 (4 crawlers per 0.8 cm square). These differences are reflected in the different color gradient scales between Figure 7 and Figure 8 (0-60 vs 2-10).

Data was taken in July 2013 and July 2014 evaluating the seedlings for adelgid infestation using the 0-5 curling scale and a binary scale indicating the presence or absence of adelgids. As expect there was a pronounced difference between the two years. In 2013, when the trees received much higher levels of infestation, adelgids could be found on most all of the trees and some of the trees also exhibited some needle curling. In 2014, presence of adelgids and curling were both much reduced compared to 2013, which is most likely due to the fact that the seedlings were exposed to much lower numbers of crawlers. Although the Nordmann fir tended to have the highest levels of adelgids and curling damage ratings, the ANOVA on this data did not show a significant difference between them and other species (data not shown).

Activity. Evaluate the effectiveness and residual activity of conventional and new insecticides for control of the adelgid. In 2014, a control trial was set up using trees in the infested 2004 Nordmann and Turkish fir genetic trial at WSU Puyallup. Five products (Table 6) were applied as foliar sprays, broadcast treatments to the soil, or direct applications to the basal bark on the stems of trees (Table 7). A single tree in each of 7 blocks was treated with each treatment. Checks consisted of a non-treated tree in each block. All treatment trees were separated from each other by at least 12 feet to prevent any effect from adjacent treatments due to overspray or runoff. Treatments were applied in April and trees were evaluated for adelgid damage as indicated in the susceptibility trials above in September. Results indicate that the foliar applications of OnyxPro and Ultor were the only treatments that significantly reduced the damage caused by the adelgids. Since adelgid treatments often provide more than one year of control, in 2015 trees that were treated in 2014 were reevaluated to determine if there was any residual activity of the treatments. The data showed that, there was no difference between the treatments (Table 8). Although the damage ratings were generally lower in 2015, this would indicate that there was no residual control from the 2014 treatments so growers would need to treat trees every year to control this pest.

Activity. Present updates to growers and collaborators at industry meetings.

- 2014 - Presentations were made to an estimated 400 growers attending the Wilbur Ellis U. Christmas Tree session in Auburn, WA (January) and the Pacific Northwest Christmas Tree Association Annual Short Course (March) and Tree Fair (September) in Portland, OR and 10 scientist at the annual NCERA 224 meeting in NC (September).
- 2015- Presentations were made to an estimated 450 growers attending the Pacific Northwest Christmas Tree Association (PNWCTA) Annual Short Course in Wilsonville, OR (March), PNWCTA Summer Tour in Rochester, WA (June), and the Puget Sound Christmas Tree Association Annual Meeting in Puyallup, WA (June); as well as 10 scientists at the annual NCERA 224 meeting in WY (September); and 60 Christmas tree scientists at the 12th IUFRO International Christmas Tree Research and Extension Conference in Honne, Norway (September).
- 2016 - Presentations were made to an estimated 400 growers attending either the Pacific Northwest Christmas Tree Association Annual Short Course in Wilsonville, OR (March), and/or the Tree Fair in Portland, OR. (September).

Activity. Analyze data, prepare project reports, articles for industry publications, and manuscripts for publication. All of the progress reports for this project were submitted on time. Handouts with photos were provided to growers at the regional Christmas tree meetings and scientist at the NCERA 224 meetings listed above. An abstract from the 12th IUFRO International Christmas Tree Research and Extension Conference in Honne, Norway was posted on the IUFRO website NIBIO BOOK 1(1) 2015; p. 22. A manuscript reporting the results of this project is being prepared for submission the Scandinavian Journal of Forest Research.

Dr. Art Antonelli, Washington State University, provided assistance in setting up the life cycle studies; Dr. Ulrik Brauner Nielsen, University of Copenhagen, assisted with the design of the seedling susceptibility trials; Chal Landgren, Oregon State University, assisted with preliminary grower surveys; Dr. Richard Cowles, Connecticut Agricultural Experiment Station, assisted in designing the adelgid control trial; and Dr. Nathan Havill, USDA Forest Service Northern Research Station, provided assistance relating to attempts to identify the adelgid.

This adelgid only causes economically important damage on Nordmann fir, which is used for Christmas tree and bough production. No non-specialty crops are affected.

GOALS AND OUTCOMES ACHIEVED

A summary of the activities completed to achieve the following goals and Expected Measurable Outcomes is provided above.

Outcome 1 – See the life cycle and GDD activities above.
Goal: Determine when various life stages of the adelgid develop on Nordmann fir in the PNW.
Target: Share a timeline for the development of life stages of the adelgid on Nordmann fir with 200 growers by the end of the second year of the project.
Benchmark: No information is available.
Performance Measure: The number of growers will be measured by attendance at presentations at annual grower meetings.

Outcome 2 – See the life cycle, GDD, host susceptibility, postharvest spread, and control activities above.
Goal: This project will result in the development of best management practice (BMP) recommendations to control adelgids on Nordmann and Turkish firs.
Target: Information will be posted on the WSU-Puyallup Christmas Tree website and shared with more than 300 growers.
Benchmark: Progress on the development of the BMPs will be reported to growers throughout the project. Performance Measure: The number of growers who receive BMP information will be measured by downloads from the website and attendance at presentations at annual grower meetings.

This project did not have long term expected measurable outcomes.

All of the activities established for this project were completed. Due to the lack of genetic differences within the Adelges piceae/nordmannianae/prelli group, it was not possible to conclusively determine by DNA sequence which of those three species of adelgid are at hand. The Outcome 1 Goal to determine when various life stages of the adelgid develop on Nordmann fir in the PNW was completed. The Outcome 2 Goal to obtain sufficient data to develop best management practice (BMP) recommendations to control adelgids on Nordmann and Turkish firs was also completed. Information relating to this project was shared with an estimated 1,250 growers at educational grower meetings. The preparation of a best management fact sheet, which will be posted on the WSU Puyallup Plant Pathology Ornamental (PPO) website is in progress.

Prior to the start of this project, there was no information relating to the biology of the silver fir woolly adelgid, host susceptibility, and effectiveness of the products commonly used in the PNW to control this pest on Nordmann fir in the PNW. Below is a summary of the achievements made on the proposed targets.

Outcome 1:
Goal: Determine when various life stages of the adelgid develop on Nordmann fir in the PNW.
Target: Share a timeline for the development of life stages of the adelgid on Nordmann fir with 200 growers by the end of the second year of the project.

- Information on the life cycle and growing degree days associated with the appearance of crawlers was shared with an estimated 850 growers at regional meetings during the first two years of this project.

Outcome 2:
Goal: This project will result in the development of BMP recommendations to control adelgids on Nordmann and Turkish firs.
Target: Information will be posted on the WSU-Puyallup Christmas Tree website and shared with more than 300 growers.

- BMP recommendations were made to 400 growers during the final year of this project.

BENEFICIARIES

Data collected indicate that the adelgid only causes economically-important damage to Nordmann fir, which is used for Christmas tree and bough production. This project will benefit the state's approximately 250 Christmas tree growers involved in producing this specialty crop.

Information from this project was presented to approximately 1,250 growers at regional meetings.

LESSONS LEARNED

Although DNA sequencing was able to narrow the identification of the adelgid to the Adelges piceae/nordmannianae/prelli group, a lack of genetic differences limited further identification. However, the combination of this information with that from the host susceptibility trials yielded a confident identification of the silver fir woolly adelgid [Adelges (Dreyfusia) nordmannianae].

The methods employed to infest the 1,400 CoFirGE seedlings were unsuccessful due to the low number of crawlers that were transferred from the infested branches to the seedlings and the uneven distribution through the different reps in the experiment. A subset of these seedlings have been transplanted to a field plot in an effort to expose them to natural spread of the adelgid. The seedlings will be monitored during the next couple of years.

The apparently natural collapse of the adelgid population and limited damage that occurred on any of the trees in the 2004 plot in 2016 was unexpected. It is unclear if this is an indication that this adelgid is not well adapted to conditions in the PNW or if populations of natural predators developed and controlled the adelgid.

Although DNA sequencing was able to narrow the identification of the adelgid to the Adelges piceae/nordmannianae/prelli group, a lack of genetic differences prevented further identification. Efforts to determine a region of DNA that would differentiate within this group is recommended. Meanwhile, researchers are advised to combine molecular identification techniques with host susceptibility trials and morphological information.

ADDITIONAL INFORMATION

The Pacific Northwest Christmas Tree Association provided a total of $15,000 in support of this project. In lieu of funds from the Puget Sound Christmas Tree Association, the Washington State Department of Agriculture Christmas tree licensing program also provided a total of $20,000 in support of this research. These funds were used to help cover a portion of the costs for temporary help, supplies, and WSU land use fees. In-kind support included a total of 1,420 seedlings from a national CoFirGE project, worth an estimated $8775, and Bob Moore, a local Christmas tree grower, donated approximately 120 hours of assistance in culturing trees in research plots at Puyallup.

Tables, Figures and Pictures

Figure 1. Nordmann fir growth exhibiting severe needle curling associated with adelgid infestation.

Figure 2. Illustration of Adelges nordmannianae life cycle.

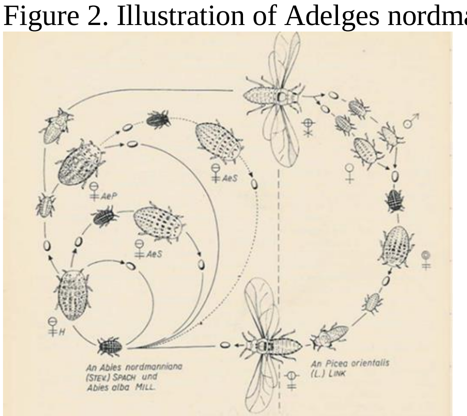

Figure 3. Neighbor joining tree showing the genetic relationship between adelgid samples collected in this study and sequences of known adelgid (voucher) species. Adelgid voucher sample names are preceded by an EF followed by the

species and the word voucher, while this study's samples are identified by species, area of host, collection site, and collection date. Branch length is proportional to the numbers of nucleotide substitutions as measured by the scale bar.

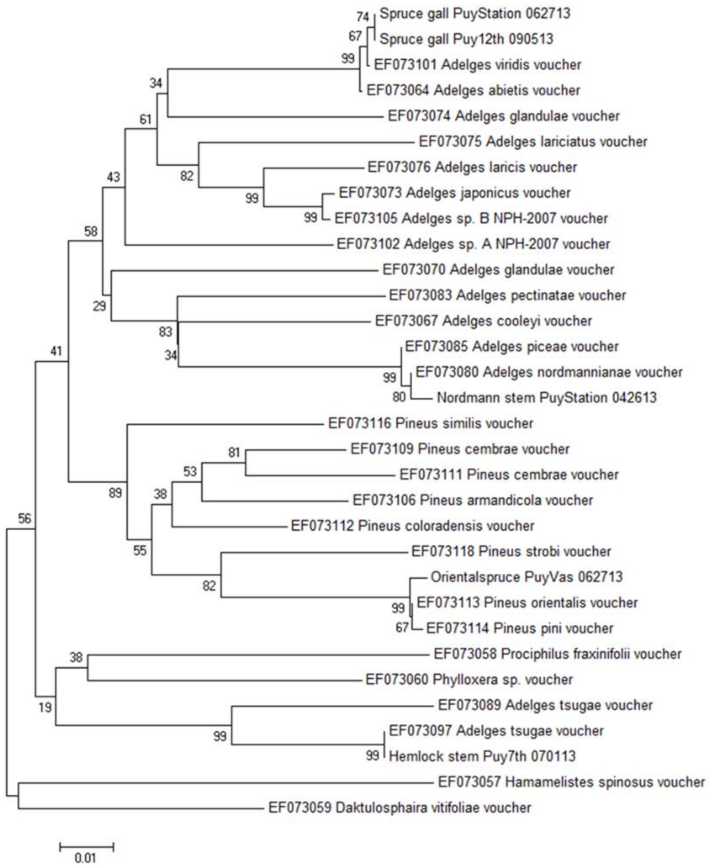

Figure 4. Life stages of adelgids observed on trees at WSU Puyallup. Overwintered stem mothers with eggs (left), crawlers (center), winged form with summer stem mother (right).

Figure 5. Plot map showing the distribution of adelgid damage on trees in the Nordmann fir elevation plot in 2014 (no fill color = no adelgid damage, gray fill = no tree, yellow fill = slight damage, orange fill = moderate damage, and red fill = severe damage).

Rep 6						**Rep 5**						**Rep 4**					
36	**35**	**38**	**33**	**37**	**34**	**36**	**34**	**35**	**38**	**33**	**37**	**35**	**38**	**33**	**37**	**36**	**34**
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

	Rep 3						Rep 2						Rep 1					
	34	**37**	**36**	**35**	**38**	**33**	**33**	**35**	**37**	**34**	**36**	**38**	**37**	**33**	**38**	**36**	**34**	**35**
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Figure 5. Plot map showing the distribution of adelgid damage on trees in the Nordmann fir elevation plot in 2015 (no fill color = no adelgid damage, gray fill = no tree, yellow fill = slight damage, orange fill = moderate damage, and red fill = severe damage).

Rep 6						Rep 5						Rep 4					
36	**35**	**38**	**33**	**37**	**34**	**36**	**34**	**35**	**38**	**33**	**37**	**35**	**38**	**33**	**37**	**36**	**34**
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
34	**37**	**36**	**35**	**38**	**33**	**33**	**35**	**37**	**34**	**36**	**38**	**37**	**33**	**38**	**36**	**34**	**35**
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Rep 3						Rep 2						Rep 1					

Figure 6. Setup showing shade cloth covering branches that were suspended over seedlings

Figure 7. 2013 contour plot showing density of crawlers captured per 0.8 cm sq.

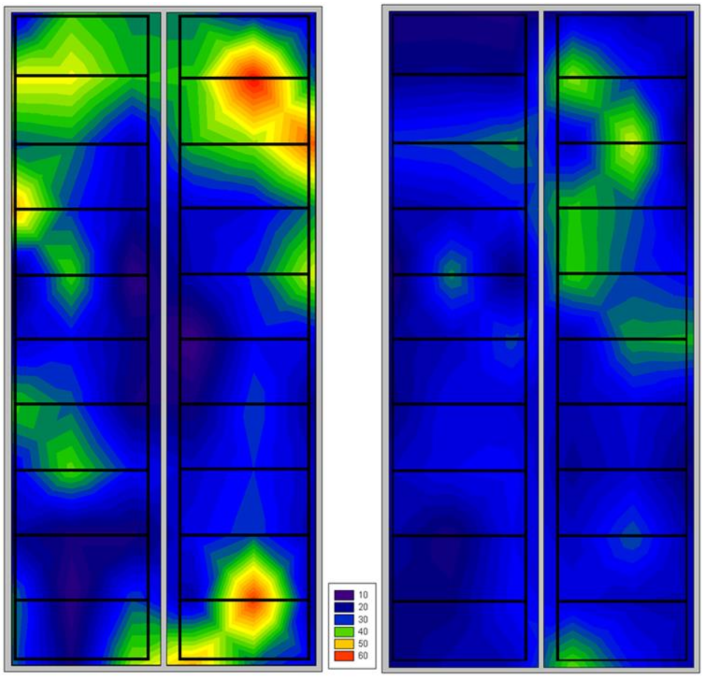

Figure 8. 2014 contour plot showing density of crawlers captured per 0.8 cm sq.

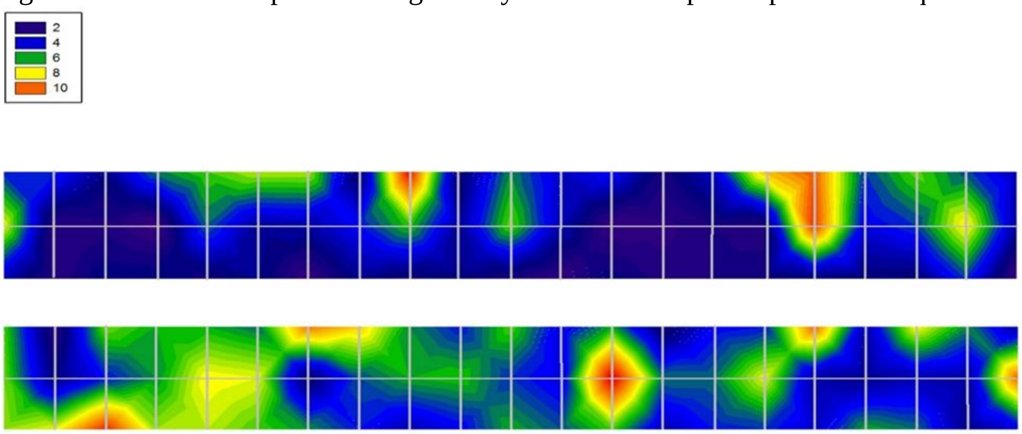

Table 1. Various stages of adelgid were collected from conifer on and nearby the WSU Puyallup campus and identified by DNA sequencing of the cytochrome oxidase I (COI) region.

Collected	Stage	Host	Area of host	Storage	Quantity	Location	Species ID by COI DNA sequence
4/26/2013	adults	Nordmann	stem	dry	~12 in one tube	WSU Puy	Adelges nordmannianae/piceae
4/26/2013	eggs	Nordmann	stem	dry	~12 in one tube	WSU Puy	Adelges nordmannianae/piceae
4/26/2013	crawlers	Nordmann	stem	alcohol	~12 in one tube	WSU Puy	Not analyzed
4/26/2013	crawlers	Nordmann	stem	alcohol	~12 in one tube	WSU Puy	Not analyzed
4/26/2013	egg mass	Nordmann	stem	dry	a mass	WSU Puy	Adelges nordmannianae/piceae
4/26/2013	adults	Nordmann	stem	alcohol	~12 in one tube	WSU Puy	Not analyzed

4/26/2013	eggs	Nordmann	stem	alcohol	~12 in one tube	WSU Puy	Not analyzed
6/24/2013	crawlers	Nordmann	unspecified	dry	14 in single tubes	Martenson	No result
6/27/2013	unspecified	Oriental spruce	unspecified	dry	14 in single tubes	Vassey Nursery	Pineus orientalis/pini
6/27/2013	unspecified	Spruce	gall	dry	14 in single tubes	WSU Puy	Adelges abietis/viridis
7/1/2013	unspecified	Hemlock	stem	dry	14 in single tubes	Puy 7th Ave	Adelges tsugae
9/5/2013	unspecified	Spruce	gall	dry	14 in single tubes	Puy 12th Ave	Adelges abietis/viridis

Table 2. Adelgid lift cycle timeline on Nordmann fir at Puyallup

	2013		2014		2015		2016	
Life Stage	Date	GDD	Date	GDD	Date	GDD	Date	GDD
1st generation eggs	26 Mar	77	26 Mar	116	30 Mar	211	28-Mar	179.8
First crawlers	3 Apr	243	9 Apr	221	13 Apr	297	14 Apr.	380
Bud break	30 Apr	371	1 May	437	20 Apr	361	11 Apr	354
2^{nd} gen. eggs	7 June	996	30 May	914	7 May	543	16 May	913
2^{nd} gen. crawler	13 June	1103	30 May	914	-	-	13 June	1447
Winged form	21 May	724	30 May	914	n/a		n/a	

Table 3. Effect of postharvest treatments on the viability of adelgids on cut Nordmann fir branches.

Treatment[1]	Mot.[2]	Eggs	Craw.	Mot.	Eggs	Craw.	Mot.	Eggs	Craw.	Mot.	Eggs	Craw.
2013-14	9-Jan.			19-Feb.			26-Mar.			9-Apr.		
1	+	-	-	+	-	-	+	+	-	+	+	+
2	+	-	-	+	-	+	+	-	-	-	-	-
3	+	+	+	+	+	+	+	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
2014-15	2-Jan.			15-Feb.			25.Mar.			13-Apr.		
1	+	-	-	+	-	-	+	-	-	+	+	+
2	+	-	-	+	-	-	-	-	-	-	-	-
3	+	-	-	+	-	-	-	-	-	-	-	-
4	+/-	-	-	-	-	-	-	-	-	-	-	-

[1]Treatment 1 = Branch on tree, 2 = branch harvested and stored outdoors, 3 = branch harvested and displayed in water for one month and then stored outdoors, and 4 = branch harvested and displayed dry for one month and then stored outdoors.
[2]Codes: Mot. = stem mother adelgid, Craw. = adelgid crawler, "+" = live life stage present, "-" = life stage absent or dead.

Table 4. Average Damage Ratings by Seed Source, 2004 Genetic Planting.

		Average Damage[1]					
Number	Source	2014		2015		2016	
8	Nordmann Fir, Denmark Statsskovenes Planteavlsstation	2.55	a	**2.00**	**a**	0.19	a
14	Nordmann Fir, Denmark Klon Hedeselskabet Forest Seed Center	2.38	a	1.13	abc	0.00	a

13	Nordmann Fir, Denmark Klon Hedeselskabet Forest Seed Center	2.26	a	0.60	cde	0.10	a
22	Nordmann Fir, Denmark Statsskovenes Planteavlsstation	2.22	a	1.12	bcd	0.13	a
17	Nordmann Fir, Denmark Klon Hedeselskabet Forest Seed Center	2.16	ab	1.90	ab	0.05	a
10	Nordmann Fir, Denmark Statsskovenes Planteavlsstation	2.15	ab	0.80	cde	0.00	a
18	Nordmann Fir, Denmark Klon Hedeselskabet Forest Seed Center	2.03	abc	0.93	cd	0.00	a
15	Nordmann Fir, Denmark Klon Hedeselskabet Forest Seed Center	1.91	abcd	1.43	abc	0.00	a
7	Nordmann Fir, Denmark Statsskovenes Planteavlsstation	1.80	abcd	1.46	abc	0.00	a
5	Nordmann Fir, Artvin, Yayla	1.30	bcd	1.00	cd	0.04	a
12	Nordmann Fir, Denmark Statsskovenes Planteavlsstation	1.19	cd	0.93	cd	0.00	a
16	Nordmann Fir, Denmark Klon Hedeselskabet Forest Seed Center	1.09	de	0.54	de	0.13	a
4	Turkish Fir, Adapazan, Akyazi	0.26	ef	0.33	de	0.00	a
3	Turkish Fir, Adapazan, Hendek	0.23	ef	0.44	de	0.00	a
1	Turkish Fir, Bursa, Komursu	0.11	f	0.00	e	0.00	a

[1] Overall damage was rated on a scale of 0 to 3, with 0 indicating no damage and 3 indicating an unmarketable tree. Numbers with the same letter are not significantly different, *P*<0.05, Tukey's Studentized Range (HSD) Test.

Table 5. Average damage ratings of 13 Abies species in a replicated demonstration planting.

	2013		2014		2015	
Species	Curling	Damage	Curling	Damage	Curling	Damage
California Red Fir	0	0	0	0	0	0
Noble Fir	0	0	0	0	0	0
Grand Fir	0	0	0	0	0	0
Fraser Fir	0.1	0	0	0	0	0
Shasta Fir	0	0	0	0	0	0
White Fir	0	0	0	0	0	0
Canaan Fir	0.1	0.1	0	0	0	0
Balsam Fir	0.9	0.2	0	0	0	0
Korean Fir	0.1	0	0	0	0	0
Nikko Fir	0.1	0	0	0	0	0.1
Turkish Fir #4	0.3	0.1	0	0	0	0.2
European Silver Fir	0.8	0.7	0.3	0.5	0.4	1.5
Nordmann Fir #13	1.4	1.0	1.8	1.6	1.4	1.5

[1]Curling was rated on a scale of 0 to 5, with 0 = no curling or evidence of adelgids and 5 = most needles are curled throughout the branch and many of the needles have a yellow or brown color. Overall damage was rated on a scale of 0 to 3, with 0 indicating no damage and 3 indicating an unmarketable tree.

Table 6. Products used in adelgid control trial.

Products	% active ingredient	Source
Ultor	14.4% spirotetramat	Bayer
Safari 20SC	20% dintefuran	Valent
OnyxPro	23.4% bifenthrin	FMC
Admire Pro	41.8% imidacloprid	Bayer
Syl-Tac	organosilicone surfactant	Wilbur-Ellis
Preference	NIS surfactant	Winfield

Table 7. Treatments rates, application sites, and application timing.

Treatments[1]	Rate	Type[2]	Timing[3]
Admire Pro + Syl-Tac	4 fl oz/A	Foliar	1
OnyxPro	6 fl oz/A	Foliar	1
Ultor + Preference NIS	16 fl oz/A	Foliar	1 &2
Admire Pro	12.8 fl oz/A	Broadcast	1
Admire Pro	25.6 fl oz/A	Broadcast	1
Safari 20SG	0.75 lb/A	Basal bark	1
Check	-	-	-

[1]Syl-Tac @ 4 fl.oz. and Preference NIS @ 0.25% v/v
[2]Sprays applied in 47.3 gal/A (foliar) or 11.9 gal/A (broadcast)
[3]Timing: 1 = April 8-11, 2014 and 2 = April 25, 2014

Table 8. Effect of adelgid treatments on 2014 needle curling and damage ratings on Nordmann fir trees[1].

			2014 Data		2015 Residual Control	
Treatments	Application site	Rate/A	Curling	Damage	Curling	Damage
Check	-	-	4.4a[2]	3.0a	1.3a	1.5a
Admire Pro+Syl-Tac	Foliar	4 fl.oz.	4.0ab	3.0a	0.8a	1.0a
Admire Pro	Broadcast	12.8 fl.oz.	4.0ab	3.0a	0.7a	0.7a
Safari	Basal bark	0.75 lb	3.0abc	2.4ab	1.0a	1.1a
Admire Pro	Broadcast	25.6 fl.oz.	2.8abc	2.8a	1.7a	1.6a
Ultor	Foliar	16 fl.oz	2.0bc	1.8bc	2.1a	1.9a
OnyxPro	Foliar	6 fl.oz.	1.4c	1.2c	1.0a	1.3a

[1]Curling was rated on a scale of 0 to 5, with 0 = no curling or evidence of adelgids and 5 = most needles are curled throughout the branch and many of the needles have a yellow or brown color. Overall damage was rated on a scale of 0 to 3, with 0 indicating no damage and 3 indicating an unmarketable tree.
[2]Columns with the same letter are not significantly different, $P<0.05$, Tukey's Studentized Range (HSD) Test.

CONTACT INFORMATION

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Partner Organization: Washington State University

PROJECT SUMMARY

The Snohomish County Agricultural Compost Research and Outreach Project (SCACROP) sought to increase the longevity and production of specialty crop farms through research, education, outreach and demonstration trials utilizing commercially produced compost as an experimental input on local specialty crops. Declining soil quality in intensive specialty crop rotations is threatening the long term productivity of the local farms. Western Washington specialty crop farmers are under considerable economic pressure to maintain intensive cash crop rotations in order to retain the farm businesses. Due to local consumer demands, these farmers wanted to reduce detrimental effects to soil and water quality, soil erosion, soil compaction, and contribution to greenhouse gases, all of which are caused by mining, rather than building, soil resources. This comprehensive, integrated project had a long term goal of increasing farmer economic and environmental sustainability in western Washington through the soil quality improvement practice of incorporating local, commercially produced compost into specialty crop production.

High annual rainfall, soil saturation, and fragile waterways pose particular challenges for specialty crop farmers in western Washington. In a region with high annual rainfall growers deal with compacted soils, saturated soil and drainage issues, (Backlund, 1995), erosion (Faucette, 2004), and nutrient runoff contributing to pollution in local waterways (Carpenter, 1998). While compost has the potential to alleviate these problems, the economic connection between local compost producers and specialty crop farmers had yet to be established. There was a lack of information on cost/benefit analysis of compost and minimal training available on the use of compost in specialty crop production. SCACROP was needed to address the disconnect between western Washington farmers and readily available commercial compost. SCACROP helped close the local nutrient cycle and returned food and yard waste nutrients to local specialty crop farmland in a time when local municipal compost companies are only selling approximately 5% of their product volume to the western Washington agricultural market.

SCACROP built upon a previous compost program that was funded from 2011-2013. SCACROP continued the previous program's work by facilitating on-farm side by side crop demonstration trials with municipal compost. SCACROP was able to increase program participants by adding additional certified organic farmers and increasing outreach and education regarding agricultural use of municipal compost. SCACROP continued to conduct farmer surveys and was able to verify barriers to compost use that were hypothesized during the previous compost program (2011-2013). Furthermore, SCACROP was able to expand the list of project partners to include Lenz Earthworks (the second largest compost producer in the county), Bailey Compost, as well as Snohomish County's Surface Water Management Division and Economic Development Team.

PROJECT APPROACH

SCACROP recruited two farmers in 2015 and 2016 for on-farm research trial collaboration. The two research trials utilized a more complex design than in previous years, going beyond the scope of the grant and providing valuable and interesting research results. SCACROP also conducted 59 demonstration trials with local specialty crop farmers and organized the distribution of 2,950 cu/yards of compost. As per the work plan, farms were visited regularly. Each trial site was visited three to five times throughout the season to collect photos and feedback and monitor trial progress. Demonstration crops included mixed vegetables, tomatoes, radishes, pumpkins, sweet corn, Christmas trees, berries, cut flowers, salad greens, herbs, squash, and more. Compost delivery timing proved to be challenging (mostly due to erratic weather patterns) but ultimately was successful. Farmers in the demonstration trials did side by side comparisons with compost vs. no compost in the same field and with the same crop. The aim was to let each farmer see for themselves how the compost would impact their crops in their fields. Surveys of the participants were conducted each year and in the WSU Social and Economic Sciences Research Center (SESRC) 2016 survey 73% claimed that compost either greatly or somewhat improved their farms profitability, 19% indicated that compost greatly or somewhat reduced the use of chemical fertilizers on their farm, and 84% of respondents may continue to incorporate compost in the future as part of their regular land management practices.

Outreach activities during the full grant period were numerous and have been detailed in previous annual performance reports. However, for perspective, prior to SCACROP there were limited western Washington specific field guides and resources available for western Washington farmers to understand how to use compost in their farming system and very little government or educational effort being allocated to discuss compost use with Snohomish County farmers. As a direct result of SCACROP there are now compost tools available for local farmers (Compost use field guide, Best Management Practices, instructional videos etc.). Furthermore, SCACROP hosted meetings and feedback sessions to improve communication between farmers and compost producers as well as farm planners and landowners who are interested in agricultural compost use. SCACROP considers these steps as evidence of progress towards increasing farmer knowledge of compost in specialty crop production.

SCACROP had 9 partners contributing to the success of this project.

- Cedar Grove, Lenz Earthworks and Bailey Compost all contributed the in-kind resource of compost to the program.
- Snohomish County Surface Water Management provided the funding to pay for the testing of soil and tissue samples gathered during the research trials.
- Snohomish County Ag. Director provided feedback on the program and free outreach space at the local Focus on Farming event each year.
- Snohomish County Office of Energy and Sustainability provided assistance in research on compost spreading equipment, document review and attendance at the annual partner meeting.
- The Snohomish County Solid Waste Division contributed in kind contributions of technical support and program promotion at conferences.
- Snohomish Conservation District provided valuable assistance in research days, program advising and demonstration trial monitoring.
- The US Composting Council Research and Education Foundation provided collaboration and guidance to the SCACROP program staff.

Project staff met with all farmers every season before they received compost and discussed with them the type of crops they planned on growing with compost. All farmers were instructed to use the compost on specialty crops. The farmers were visited a minimum of two other times throughout the growing season to insure that the compost was only used on specialty crops. This allowed for farmers to see for themselves the benefits of compost on specialty crops.

GOALS AND OUTCOMES ACHIEVED

SCACROP outlined three expected measurable outcomes in the grant project. Some of these outcomes have more than one specific benchmark and some are more focused on long term goals. The following paragraphs will outline each measurable outcome, and the activities taken to meet that outcome.

Outcome 1: Increase the number of famers in Snohomish County using compost on specialty crops. SCACROP visited more than 200 farms in Snohomish and King Counties and encouraged them to participate in the compost trials. Every farm that participated in the program had signs displaying to the public their participation in the demonstration trials. Outreach was conducted at local community events, like the Evergreen State Fair and Focus on Farming to encourage more farmers to use compost on their specialty crops. SCACROP created educational compost videos that are featured on a Washington State University Snohomish County Extension website (http://extension.wsu.edu/snohomish/agriculture/compost/watch-our-youtube-films/). This combined outreach effort helped increase farmer knowledge of compost utilization in specialty crop production.

Outcome 2: Increase specialty crop production in Washington through the use of commercially-produced compost. SCACROP addressed this outcome by providing farmers with commercially produced food and yard waste compost that was then used on specialty crops. SCACROP arranged for the delivery of the commercial compost to program participants at no cost to those participating farmers. The compost was offered in conventional and organic blends to meet the needs of a wider audience of farmers. In addition, SCACROP was responsive to initial farmer feedback and began providing double screened compost to help reduce contaminants and larger woody material. SCACROP also created a Best Management Practices handout that was provided to farmers to aid them with compost application rates, methods, and timing for incorporating compost on specialty crops. Finally SCACROP helped develop and distribute a field guild entitled "Fertilizing with Manure and other Organic Amendments," shown below in the "Additional Information" section.

Outcome 3: Increase resilience of local specialty crop farmland through enhanced soil quality, increased water infiltration rates and reduced run-off.
Two farmers were recruited to collaborate in on-farm research trials in 2015 and 2016 using sweet corn as a crop. These four research trials utilized a more complex design than in previous years; a split block design was used to analyze compost by fertilizer interactions. In addition to compost and no compost treatments, nitrogen fertilizer was applied at staggered rates including 0x the recommended rate, 1/2x, 3/4x, and 1x the recommended fertilizer rate (based on soil tests). Planning meetings were held with each farmer and experimental sites were chosen for each trial. Plot marking, soil samples, and compost application for each trial took place in 2015 and 2016. Data collection included: pre-plant, mid-season, and post-harvest soil nitrate testing; corn biomass, ear weight, ear quality, and nitrogen content; and soil bulk density and infiltration testing. Data analyses are still underway, but the research design should indicate whether any yield increases due to compost were provided by an increase in nitrogen availability alone or if general enhancement of soil quality provided a synergistic effect.

Increasing the resilience of local specialty crop farmland through enhanced soil quality, water infiltration rates and reduced run-off are considered a long-term expected measurable outcome. It may take years of continual compost application to a field in order to observe these benefits. SCACROP believes that by providing farmers with compost and inspiring them to continue to use compost after the program is over, that farmers will increase the resilience of their farmland.

Project Activity	**Responsible Party**	**Timeline (*month and year*)**	**Actual Accomplishment**
Develop participant list, outreach plan and materials for recruitment of new and revisiting existing specialty crop participants. Begin outreach. Integrate compost education and outreach programs with volunteer outreach efforts, including developing, updating, printing/uploading and distributing outreach materials.	WSU Extension (WSUE) and Snohomish Conservation District (SCD)	Oct. – Nov. 2013	Completed
Farmer recruitment for 2014 season, create timeline, plan educational workshops, outreach at conferences and community events.	WSUE, Snohomish County (SC) and SCD	Dec. 2013- Feb. 2014	Completed
Farm visits, compost deliveries and application, begin research and demonstration trials.	WSUE, Farmers, Compost Producers and SCD	Feb.- May 2014	Completed
Monitoring and data collection for demonstration and research trials, host workshops, video/photo testimonials and documentation.	WSUE and SCD	June- Aug. 2014	Completed
Season wrap up & survey, research site data collection, report, website, create short video from testimonial and documentation footage.	WSUE and SCD	Aug. – Nov. 2014	Completed
Recruitment for 2015 season, refine timeline, plan educational workshops, outreach at conferences and community events.	WSUE, SC and SCD	Dec. 2014- Feb. 2015	Completed
Farm visits, compost deliveries and application, begin research and demonstration trials.	WSUE, Farmers, Compost Producers and SCD	Feb.- May 2015	Completed

Monitoring and data collection for demonstration and research trials, host field days and workshops, video/photo testimonials and documentation.	WSUE, SC and SCD	June- Aug. 2015	Completed
Season wrap up & survey, research site data collection, report, website development.	WSUE and SCD	Aug. – Nov. 2015	Completed
Recruit for 2016 growing season, refine timeline, plan educational workshops, outreach at conferences and community events.	WSUE, SC and SCD	Dec. 2015- Feb. 2016	Completed
Farm visits, compost deliveries and application, begin research and demonstration trials. Begin development of Compost Field Guide.	WSUE, Farmers, Compost Producers and SCD	Feb.- May 2016	Completed
Monitoring and cumulative data collection for demonstration and research trials, host field days/workshops, video/photo testimonials and documentation, begin drafting peer-reviewed article and continue Compost Field Guide.	WSUE, SC and SCD	June- Aug. 2016	Completed
Project wrap up & survey, research site data collection, create cohesive report for three years of trials, website, short film on findings for three years of trials, complete and distribute Compost Field Guide, and prepare manuscript submission to peer-review journal.	WSU and all partners	Aug. – Sept. 2016	Partially-Completed

Outcome 1: Increase the number of famers in Snohomish County using compost on specialty crops.
The original metric was an achievement of 60 specialty crop growers participating in the three year program.
Rather than 60 individual farms participating in the trials, at least 60 trials or 'site years' was achieved. Some of the completed trials took place on the same farm site over multiple years to encourage repeat compost applications and ongoing involvement in the program. As has previously been reported in the annual performance reports the Compost Trials Program has an additional funding source, the Coordinated Prevention Grant, administered through Snohomish County. This funding in conjunction with the SCBGP funding enabled SCACROP to work with a total of sixty-five individual farm participants over the course of 3 years. In 2013 only 20% of program respondents indicated that they had used food and yard waste prior to their participation in the SCACROP program. The original metric was a target of 80% of respondents plan to utilize compost in their operation after SCACROP. In the final survey of program participants (SESRC 2016) (see "Additional Information" section below), 84% of responding participants indicated that they may continue to incorporate compost as a part of their future land management practices.

Outcome 2: Increase specialty crop production in Washington through the use of commercially-produced compost.
The original metric benchmark for increasing specialty crop production was a 20% crop yield increase for pumpkins and 70% of program participants seeing increases in yield. SCACROP research with compost application results are as follows:

<u>2014 research</u>: Compost applications to cucumbers were tested and found that with an addition of 27.5 dry tons of compost per acre an additional 0.82 tons of cucumbers per acre were produced. Organic green bean production was also tested in 2014. Organic compost was added to the field at a rate of 24.8 cubic yards per acre and resulted in a 19% (0.64 ton/acre) increase in yield compared to the control. In 2014 SCACROP also tested municipal compost impacts on beet seed production. Compost was applied at a 55 cu yd/acre application rate and resulted in a 21% increase in yield.

<u>2015 research</u>: SCACROP completed two research trials on sweet corn utilizing 7.8 and 8.6 dry tons/acre of municipal compost and 4 different rates of nitrate fertilizer. Both studies found that the ground where the corn was planted already had significant available nitrogen to grow corn, likely due to a history of manure application, and no significant nitrogen or compost effect was detected at either site. However, it was found that compost reduced bulk density at both sites, indicating that compost had a positive influence on the soil's physical properties.

2016 research: SCACROP again conducted research trials on sweet corn. This time an effort was made to find fields that had been underperforming in the past. At the first site, a notable compost effect was detected for both corn ear weight (p value=0.074) and corn biomass (p value = 0.097), along with a significant fertilizer effect for ear weight (p value = 0.043). Across all fertilizer treatments at the first site, compost increased corn ear weight by 19% and at the highest nitrogen application rate compost increased corn ear weight by 45%. At the second research site there was a compost by fertilizer interaction for ear weight (p value= 0.076); at the two lowest fertilizer rates (0x and 0.5x) compost resulted in an increase in ear weight (p value = 0.059 and p value = 0.049, respectively). Once processed, soil nitrate and corn nitrogen content results should help us interpret and explain the increased yield with compost.

The final measurement of achievement of Expected Measurable Outcomes regarding crop production is available via the 2016 SERC survey. In the survey, 83% of farmers in demonstration trials reported that compost either greatly or somewhat improved their specialty crop production. In addition, 73% of responding farmers reported that compost improved their farm's profitability.

Outcome 3: Increase resilience of local specialty crop farmland through enhanced soil quality, increased water infiltration rates and reduced run-off.
For the two research trials the original metric benchmark was increasing resilience of farmland via water infiltration rates and soil nutrient qualities. 2013 research trials revealed that infiltration rate testing was time consuming and did not prove to be a useful indicator of soil quality. It was thought that infiltration testing might be performed at the end of the three-year grant cycle, testing only those research sites that received additional compost each year. However, during the course of the project it was determined to forgo infiltration rate testing on demonstration trials and instead focus efforts on interactions between nutrient availability and soil quality in the research trials. Infiltration was evaluated in the 4 research trials conducted during 2015 to 2016. Each site received just one application of compost (not multi-year experiments) and no differences in infiltration rates were detected.

For the demonstration trials the original metric benchmark was 90% of participants will experience enhanced soil quality, nutrient retention and increased water infiltration rates. In the June 2014 survey, 95% of demonstration trial participants reported that the compost had improved or greatly improved their soil quality. In the SERC 2016 survey of demonstration trial participants, 97% reported that compost improved their soil quality and 84% reported that compost improved their soil's water retention capabilities.

BENEFICIARIES

The primary beneficiaries of the SCACROP program are the participating specialty crop farmers. SCACROP provided farmers a first-hand opportunity to use food and yard waste municipal compost in their fields and see the benefits of compost on their crops. The WSU extension and larger academic communities will benefit from the results of the farm research trials. And ultimately the environment is a beneficiary of approximately 3688 yards (1844 tons) of food and yard waste being diverted from the local waste stream and returned as critical nutrients back to the agricultural landscape as compost.

The farmers associated with the SCACROP program received compost at an estimated value of $60,447.54. They also are the beneficiaries of a $10,000 King County funded compost cost benefit analysis. The compost companies that donated to SCACROP received the 2016 SERC survey of farmers valued at $5,000 and an unknown value of positive publicity regarding their involvement in the program.

LESSONS LEARNED

SCACROP positive lessons as a result of completing this project included:

- Compost generally does have a beneficial impact on crop production and soil quality.
- The ability to spread compost has a large bearing on whether or not a farmer will use compost.
- The use of compost with certain specialty crops may or may not help the farmer break even or yield a net gain. For example it was found that the compost breakeven price for green beans in the 2014 trial was $12.58 per yard of compost and $4.80/ yard of compost for beet seed.
- Compost on u-pick Christmas trees showed excellent growth and may be a future market for municipal compost.

SCACROP negative lessons as a result of completing this project included;

- Farmers in western Washington are generally not willing to pay the breakeven price that compost producers require largely because they have been accustomed to receiving free manure or other waste nutrient products.
- Farmers generally indicated that they would not use municipal compost on root crops for fear that the root crop would grow around any plastic contamination in compost.
- Environmental challenges of western Washington farms (smaller, wetter, more nutrient rich fields than eastern Washington) were part of the barrier to western Washington farmers purchasing and using compost on their fields.
- Fields with a history of manure or compost application are less likely to observe a yield increase with compost application.

SCACROP did not expect to find Christmas tree farmers to report such positive results from their demonstration trials. SCACROP also anticipated that the farmers would be more willing to purchase compost on a large scale after the program ended. However, it may be that many smaller organic farmers will continue to use compost as part of their standard farm practices, while larger acreage conventional farms may only purchase compost for fields that are in need of rehabilitation or water retention.

As previously noted in the annual performance reports, significant delays during the production of the extensive 3-part "Learning from the Composters" film made the original SCACROP goal to create a second film that focused on the 3-year research findings unattainable. Lessons learned would include budgeting more time and resources for film production (scripting, editing, shooting, reshooting, legal/release processes, etc.) However, due to the availability of funds and flexibility of WSDA, SCACROP was able to shoot a second short high quality film with one of the participating King County farmers. This second film does an excellent job highlighting some of the successes of SCACROP program and provides a glimpse at the world of municipal compost on a small organic specialty crop farm.
(See http://extension.wsu.edu/snohomish/agriculture/compost/)

SCACROP will submit an article about the research trials in early 2017 to the peer-reviewed journal *Compost Science and Utilization*.

ADDITIONAL INFORMATION

Overall SCACROP had a total of $183,352.00 obligated as either a cash or in kind match. SCACROP ended the program with $180,282 total match listed below:

Washington State University-facilities and overhead fees for a total of $53,062.

Snohomish County Conservation District provided staffing assistance and compost outreach for a total of $18,764.

Snohomish County Office of Energy and Sustainability provided research assistance and program feedback for a total of $13,182.35.

Snohomish County Public Works Solid Waste Division assisted in collaboration between local food and yard waste haulers and the WSU SCACROP program participated in overall coordination and review of activities for a total of $24,120.21.

Snohomish County Office of Economic Development, provided program guidance, research and reviewing program deliverables for a total of $1,989.

Compost Council Research and Education Foundation provided program guidance, research and reviewing of program deliverables for a total of $2,725.

Snohomish County Public Works: Surface Water Management provided the funding to pay for soil and tissue sample tests for a total of $5,991.90.

Lenz Enterprises provided compost for a total contribution valued at $27,727.04.

Cedar Grove Composting provided compost for a total contribution valued at $22,704.50.

Bailey Compost provided compost for a total contribution valued at $10,016.00.

Biocycle Article: Commercial compost application on western Washington Farms. (See below)
Other fact sheets created for the projects can be downloaded at the SCACROP website: http://extension.wsu.edu/snohomish/agriculture/compost/

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https://puyallup.wsu.edu/soils/wp-content/uploads/sites/411/2016/07/Paper_FertManure2016.pdf

For more information on Compost Trials in Agriculture; A Survey of Study Participants (Data Report 16-54), please go to http://www.sesrc.wsu.edu.

WSU Compost Outreach Project
Recommended Best Management Practices for Compost Use (Working Draft) January 2016
WSU Snohomish County Extension

Incorporating Compost into Fertility Plan

1. Obtain Compost Analytical Data/Nutrient Analysis from compost producer.
2. Determine the amount of Nitrogen you desire to supply with your compost application. Use one of these methods to determine Nitrogen need:
    a. Soil lab recommendations: Conduct soil sampling in the field where you plan to add compost, provide information about previous crop and crop you will be growing in the amended soil. (The lab recommendation may not be as accurate if a cover crop is utilized or if organic matter has been applied regularly over previous seasons).
    b. Most reliable method: Determine Nitrogen required for a certain crop, taking into account N from soil OM and N from a cover crop.[3] (See Table 2, on page 5).
3. Upon delivery of compost, delivery driver should provide delivery ticket with weight and estimated volume of compost received along with the most recent compost testing data. If not provided upon delivery, this information can be provided by composter.
4. Determine NPK nutrient value of compost (using Compost Analytical Data sheet, provided upon request by the compost producer), by looking at the % values in the “As Rcvd” column and converting them to lb/ton through the following steps:
    a. Nitrogen
        i. Multiply the % total Nitrogen of the compost (provided in the compost analytical data) by 20 to get lb of N wet ton of compost.

    Ex: .94% total N x 20= 18.8 lb of N/wet ton of compost (enter into worksheet on line D).

% total N Your value: _

x 20 =________lb of N/wet ton of compost

(Enter this ^ value into worksheet on line D)

b. Phosphorus (P_2O_5)
   i. Multiply the % by 20 to get lb/wet ton (enter into worksheet on line E).
c. Potassium (K_2O)
   i. Multiply the % by 20 to get lb/wet ton (enter into worksheet on line F).

5. Follow the steps in the worksheet to determine the compost application rate needed to meet the nitrogen needs of your crop.
   a. You may need to base rates on P to avoid excessive P in the soil, and supplement with other N sources to meet the total crop N requirement.

Table 1: Work sheet for Calculating Compost Application Rate

Worksheet for Calculating Compost Application Rate:

Example: I am growing sweet corn and the recommendation is 100 lbs/acre of Nitrogen. I have compost that contains 18.8 lbs of N, 6.4 lbs P, and 11.6 lbs K per wet ton of material.

#	Step	Units	Example	Your Value
A	Type of material		Food & Yard Waste Compost	
B	Crop		Brassicas	
C	Desired N application rate	lb N/acre	85	
D	Compost N concentration (from laboratory analysis).	lb N/ ton as-is	18.8	
E	Phosphorus concentration (from laboratory analysis).	lb P_2O_5/ton as-is	6.4	
F	Potassium concentration (from laboratory analysis).	lb K_2O/ton as-is	11.6	
G	Plant availability of N in compost	Percent	7	7
H	Calculate compost available N Line D x (line G/100)	lb N/ton as-is	1.3	
I	Calculate application rate Line C/line H	wet tons compost/acre	65	
J	Calculate the amount of phosphorus applied Line I x line E	lb P_2O_5/acre	416	

K	Calculate the amount of potassium applied Line I x line F	lb K_2O/acre	754

Worksheet adapted from PNW0533 Fertilizing with Manure
http://cru.cahe.wsu.edu/CEPublications/pnw533/pnw533.pdf Andy Bary, Craig Cogger, Dan M. Sullivan, 2000.

Calibrating your rear discharge manure spreader to achieve desired application rate:

6. (Manure spreader calibration can be done using this method or the method defined in step 7). Use Tarp Method to determine actual compost application rate:
    a. Measure tarp to determine square footage (area), record the tarp area
        i. use a tarp that is no wider than the spreader spray pattern
    b. Record original weight of tarp or container you will utilize for weighing
    c. Place tarp on ground in the pathway of the tractor and manure spreader
    d. Drive over the tarp in a single pass and spread compost evenly over the tarp
    e. Gather tarp and take care to contain all compost in the tarp
    f. Weigh the compost, subtract the weight of the tarp or bucket, and record the weight
    g. Divide the weight of the compost by the tarp area to get lbs. of compost per sq.ft. Ex: 75 lb of compost / 144 ft2 = 0.5 lb of compost per sq. foot

Your Value: (lb of compost) / _ (lb of compost per sq ft) (size of tarp in sq ft) = _

    h. Convert to lb per acre. There are 43,560 sq. ft. per acre.

Ex.: 0.5 x 43560 = 21,780 lbs of compost per acre (or 11 wet tons/acre)
Your Value: _(lb of compost per sq ft) x 43560 =(lb of compost per acre) (Divide by 2000 to get wet ton per acre)

    i. Adjust your application equipment settings, or make multiple passes with the spreader to achieve desired compost application rate
    j. Use actual compost application rate to determine actual quantity of nutrients applied. (see worksheet in table 1)

**To convert cubic yards of compost to tons or tons to cubic yards, utilize this conversion rate: 1150lb/cu yd or find actual bulk density by following step 7a (below).

7. Use compost Bulk Density and spreader capacity to determine application rate (Bulk Density of compost can be calculated from Compost Analytical Data or you can use the assumed Bulk Density of 1150 lb/cu yd):
    a. Find the "As Rcvd" Bulk Density of the compost by referencing the Compost Analytical Data sheet. Bulk Density is provided in lb/cu ft. (Ex: 39 lb/cu ft)
    b. To convert the Bulk Density to lb/cu yd multiple the provided number by 27. (Ex: 39 lb/ cu ft x 27= 1053 lb/ cu yd)
    c. Determine the capacity of the manure spreader. If capacity is provided in bushels, divide the bushels by 21.7 to find capacity in cubic yards.

   d. Multiply the spreader capacity by the Bulk Density of the compost to determine the weight of a full load of compost. (Ex: if spreader capacity is 2 cu yds x 1053 lb/ cu yd= 2106 lb of compost in one full manure spreader load)
   e. Spread a load on the field in a rectangular pattern and measure the length and width covered by one full load. Multiply the length and width to determine sq footage of the covered area. (Ex: 100ft length x 6ft width= 600ft2)
   f. Divide the weight of the compost in the spreader by the square footage of the covered area to determine lb/sq ft of actual compost applied. (Ex: 2106lbs / 600ft2= 3.51 wet lb/sq ft)
   g. Convert to tons/acre by multiplying the wet lb/sq ft of actual compost applied by 21.78. (Ex: 3.51 lb/sq ft x 21.78 = 76.45 wet tons/acre)
   h. Modify the application rate through tractor or manure spreader adjustments.
   i. To convert wet tons/acre to dry tons/acre assume a compost moisture content of 50% and divide by two (Ex: 76.45 wet tons/acre ÷ 2= 38.2 dry tons/acre). 5
8. Once compost is applied, it's recommended to incorporate the compost into the soil within twelve hours. If top-dressing a pasture or hay field, use a harrow.
9. After incorporating compost, wait at least 10 days before planting for annual crops. This allows compost to stabilize in the soil and nutrients from compost to become available to plants.

General Compost Use Recommendations:

1. Know the needs of your crops and the current soil nutrient content.
2. Compost application rate can be determined based on your **goals** (listed in order of lowest to highest compost application rate)*:

*Compost can be assumed to have 50% moisture content.

   a. -**improve health/microbial life**, 7 - 70yds^3/acre (2 - 20 dry tons/acre*) **(lowest rate)**
   b. -**nutrients: N,P,K, micros**, determine rate using compost nutrient content and crop needs (steps 4-8 above)
   c. -**increase organic matter**
   d. -**nursery and planting bed establishment**, ½ - 3 inch layer or 30 – 200 yds^3/acre (9-60 dry tons/acre*)
   e. -**reclamation:** increase productivity of crop land, 1 - 2" layer or 200+ yds^3/acre (60+ dry tons/acre*)
   f. -**mulch**, 1-2 inch layer or 200+ yds^3/acre (60+ dry tons/acre*) **(highest application rate)** [1]

   *Assumptions: 1 yd^3 weighs approx. 1150lbs and has 50% moisture content

3. For annual crops, apply and incorporate compost 10 days prior to crop planting to ensure the compost is stabilized and nutrients are available to the crop(s).
4. Rear discharge manure spreaders are a common tool for field application of compost.
5. Incorporation of the compost is recommended whenever possible. Incorporating compost within 12 hours of application is important to reduce Ammonium-N volatilization losses. [2]
6. Establishing new planting beds:
   a. New planting beds can benefit from one to three inches of compost incorporation to improve the soil's physical properties. [3]
7. Yearly compost application:
   a. Smaller amounts are needed to maintain organic matter and soil fertility (ie, ¼–½ inch). [3]
8. Compost will provide approximately 1.3 lb Total N /wet ton compost, 6.4 lb P_2O_5/wet ton of compost, and 11.6 lb K_2O/wet ton of compost in the first season after application (calculate nutrient values from Compost Analytical Data, see worksheet in Table 1 above), additional nutrients may need to be supplied using other fertilizer sources with plant available nutrients.

Table 2: Calculating the amount of nitrogen (N) fertilizer needed (lb/A) for a vegetable crop when taking into account soil reserves and cover crop contributions.

Fertilizer N needed	=	Crop demand (lb N/A)	- [	N from soil organic matter (lb /A)	+	N from cover crop (lbs N/A)	]
Example:							
Fertilizer N needed	=	85 lb N/acre					
Fertilizer N needed	=	225 lb N/acre (Nitrogen needed for brassicas crop)	- [	70 lb N/acre (moderate organics applications over recent seasons)	+	70 lb N/acre (legume cover crop, dense stand)	]
Solving for this number indicates how much N application is needed for this growing season.		Obtain recommended fertilizer application rates from production guides. Ex: *The Pacific Northwest Vegetable Production Guides* (Oregon State University 2012)		Depends on soil management. Range of N yielded by soil OM: 50 to 200lb N/acre Regular organic matter inputs lead to higher end of the range= 200, moderate applications of organics lead to lower N mineralization= 70 lb N/acre. [3]		Did you plant a cover crop? If no, use a 0 in this category. Typical values for PAN are 30 to 70 lb N/a for winter cereal/legume cover crops killed in mid-April. [6]	

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Compost Use In Agriculture

YIELD BENEFITS

Commercial Compost Application On Western Washington Farms

WSU Cooperative Extension in Snohomish County's Compost Outreach Project has worked with over 70 farmers since 2011 doing research trials and on-farm demonstrations.

Doug Collins, Hallie Harness and Andy Bary

Photos courtesy of Washington State University Extension

In the 2015 research trials, compost made from yard trimmings and food scraps was applied to fields at "Farm B" at a rate of 8.6 dry tons/acre.

WITH over 13 commercial composting facilities, and over 900,000 tons of food scraps and yard trimmings composted annually at these operations, western Washington is at the forefront of organic materials recovery. Although compost is available on a large scale, agricultural markets make up less than 5 percent of the total compost market in Washington State. The Washington State University (WSU) Compost Outreach Project is working to evaluate the benefits of compost on local crops and address the challenges faced when using compost.

Since 2011, WSU Cooperative Extension in Snohomish County (WA) has collaborated with local compost producers, county offices and local Conservation Districts to promote and evalu-

ate use of commercial food scraps and yard trimmings compost on farms in Snohomish and northern King County (WA) through compost use trials. While

while demonstration trials provide the opportunity for farmers to get firsthand experience using commercial compost and test it out in their operations.

es of organic matter, in 2015, 81 percent of farmer respondents (35 out of 43 WSU Compost Trials Participants) had not used food scraps and yard trimmings compost prior to participating in the trials. Local compost producers, Bailey Compost, Cedar Grove Composting and Lenz Enterprises, have donated over 4,500 tons of compost to the project since 2011, with the goal of expanding its use in agriculture.

The research trials and on-farm demonstrations conducted as part of the Compost Outreach Project are described in this article. Scientific research trials validate use of compost on local crops,

with farmers in Snohomish and King Counties have revealed several challenges to using compost. The most significant barriers to using more compost in agriculture are compost price, compost spreading (time and equipment), and lack of information.

PRE-2015 RESEARCH TRIALS

Research trials conducted through the program prior to 2015 compared two treatments: A growers' Business As Usual (BAU) chemical fertilizer application vs. BAU + Compost. Trials took place on several farms in Snohomish County. At Carleton Farm, trials evaluated the effect of cumulative multiyear compost applications. In 2012,

proximately 20 dry ton/acre) increased pumpkin yield by 28 percent. In 2013, with three years of compost application

weight increased by 24 percent. In 2014

post was applied and the three previous years of compost application resulted in

In 2014 at Darrell Hagerty Farms, a light application rate (6.5 dry tons/

creased organic green bean yield by 19 percent. Beet seed at Williams Farm showed a 21 percent increase in yield

with a 20 dry ton/acre application. Each of these results was statistically significant and utilized commercial food scraps and yard trimmings compost.

ON-FARM DEMONSTRATIONS IN 2015

There were 49 demonstration trials in 2015, which involved qualitative observation of crop growth with compost applied next to a no-compost treatment. Crops included sweet corn, hay, mixed

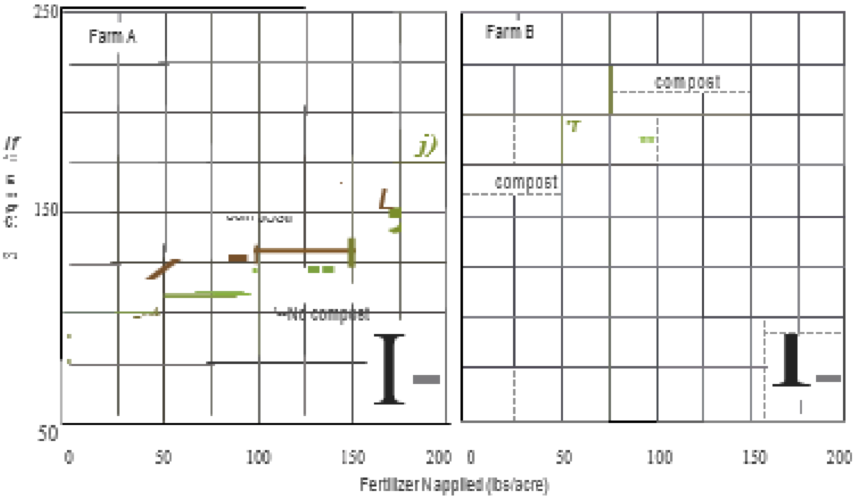
Table 1. Soil physical and chemical parameters at on-farm experiments in 2015

	Farm A	Farm B
Organic matter %	5.7	7.3
Bray P (ppm)	38	130
K (ppm)	178	366
pH	5.7	5.4
Texture	Puget silty clay loam	Puget silty clay loam

vegetables, berries, tomatoes, pumpkins, Christmas trees, salad greens, cut flowers, hazelnuts, brassicas, and more. Farmer feedback was collected through the Compost Outreach Project's annual survey (conducted since 2012). Farmer collection of yield and/or soil testing data is optional in the demonstration program. While the drought in 2015 posed significant challenges, farmers reported that compost improved crop production in 68 percent of the trials (out of 47 trial crops). Fifty-five percent of farmers found compost increased soil water retention.

Christmas tree farmers have observed improved tree growth and health and hope to sell the trees mulched with compost earlier than anticipated, which translates to potential increased profit for these growers. A farmer using compost on sweet peppers reported larger and more productive plants; blueberry plants have thrived in rows mulched with compost, and compost consistently has shown positive crop yield and

Figure 1. Mid-season soil nitrate (mg/kg) with different spring fertilizer applications and with and without compost on two western Washington farms, 2015 (bars are standard error of the mean)



health results on pumpkins. Several participants reported that the compost did nothing, i.e., there was no obvious observable effect of the compost on the crops. These are just a few highlights of the 2015 demonstration trials.

2015 RESEARCH TRIALS

Experimental Design

Research trials in 2015 were designed to evaluate the nitrogen contribution from compost as well as changes to soil physical properties on two separate farms with sweet corn as a crop. The design was a replicated strip-plot experiment where compost was either applied or not applied in strips and nitrogen fertilizer (urea) was broadcast preplanting at four different rates within the strip, including a zero-N application. The authors hypothesized that compost would compensate for some nitrogen deficiency through mineralization of the organic nitrogen in compost to plant-available nitrogen.

A different high rate of nitrogen fertilizer was chosen at each farm based on preseason soil testing and estimated nitrogen contribution from organic matter. In addition to the high rate, three other rates were applied for a total of four, where "X" is the full rate: 1.0X, 0.75X, 0.5X, and 0.0X. Corn ear weight, plant biomass, soil nitrate concentration, and bulk density were evaluated. Soil nitrate concentrations are an indication of nitrogen availability for plant uptake.

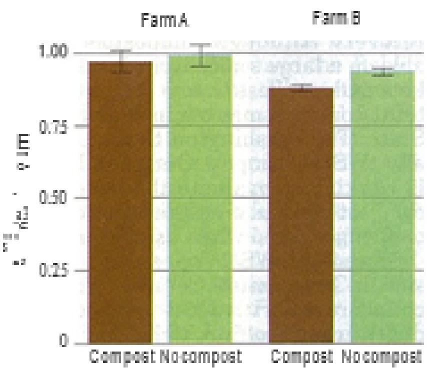
The two collaborating farms ("Farm A" and "Farm B") have been involved in the Compost Outreach Project since 2011. At Farm A, compost (from Cedar Grove) was applied at a rate of 7.8 dry tons/acre and at Farm B, compost (from Bailey) was applied at a rate of 8.6 dry tons/acre. The difference in application rates was due to differences between manure spreaders used at each farm. At Farm A, the 1X rate of nitrogen was 196 lbs/acre and at Farm B the 1X rate was 100 lbs/acre. Other pre-experiment soil properties are shown in Table 1.

Results

Neither corn ear weight or plant biomass were significantly affected by fertilizer or compost. Mid-season soil nitrate concentrations were not affected by compost, but were significantly affected by fertilizer nitrogen application (Figure 1).

The mid-season soil nitrate test was meant to be taken around the same time that farmers would test their soil to decide if a sidedress application of nitrogen is necessary. This test, also known as the pre-sidedress nitrate test (PSNT), can be used to guide mid-season nitrogen applications. Fertilizer rates should be made based on soil nitrate levels when sweet corn is at the five or six leaf stage. If soil nitrate levels are less than 10 ppm, then as much as 145 lbs N/acre are recommended. If mid-season nitrate levels are greater

Figure 2. Bulk density with and without compost application, 2015



than 40 ppm, then perhaps no fertilizer nitrate is necessary (Hart, 2010).

Mid-season nitrate levels were nearly 100 and 175 ppm at the zero nitrate fertilizer rate, much greater than what would suggest that crops would likely be deficient in nitrogen. There was likely no compost or fertilizer effect on crop yield because of naturally high levels of available nitrogen from previous management. Fields with a history of application of manure or other organic amendments are not likely to result in a yield increase from compost. In previous experiments on different fields, compost resulted in a 20 percent or larger increase in yield on several specialty crops.

Bulk density was decreased by compost applications at both farms, though the effect was only significant at Farm B where there was a 6 percent decrease (Figure 2). Bulk density (weight/volume) is a measure of soil compaction. Practices that improve soil structure such as cover cropping, reduced tillage, or organic matter application, can reduce soil bulk density. The 2015 research study designed to evaluate the effects of fertilizer and compost use will be repeated again in 2016.

ADDITIONAL PROJECT ACTIVITIES

Farmers have continually pinpointed compost price, spreading (equipment and time), compost delivery, plastic contamination of compost, and lack of information as challenges to using compost. Educational workshops and present ations have increased farmer knowledge of when and how to use compost. An ongoing dialog with composters and farmers is shaping a mutually beneficial relationship. Conservation Districts continue to enhance their focus on compost education, targeting farmers and landowners. Snohomish and King County Solid Waste Divisions, with support from Waste Management, continue to develop and expand the agricultural end use market to ensure the success of the local composting industry and the continued availability of compost for use on local farms.

Nitrogen fertilizer was applied at different rates in the 2015 trials based on preseason soil testing and estimated nitrogen contribution from compost.

The Compost Outreach Project has achieved notable success, working with nearly 73 farmers since 2011. In 2015 62 percent (23 out of 37 participating farmers) reported that they are motivated to continue using compost and nine farmers purchased loads of compost outside of the program in 2014 and 2015.

The Compost Outreach Project continues to leverage diverse funding sources and partners to break down barriers to increased farmer use of compost. Financial support comes from Snohomish County, a Washington State Department of Agriculture Specialty Crop Block Grant, and King County. Additional partners include Snohomish and King Conservation Districts, compost producers, and Waste Management.

Doug Collins is Extension Specialist at Washington State University.

Compost Outreach Project at WSU Snohomish County Extension. Until recently, Hallie Harness was the Program Coordinator of the Andy Bary is Soil Scientist at Washington State University Puyallup.

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Project Title: Integration of Weather Predictions into AgWeatherNet

Partner Organization: Washington State University (WSU)

PROJECT SUMMARY

The Washington Tree Fruit Research Commission has been instrumental in establishing AgWeatherNet (AWN) in support of tree fruit production in the State of Washington. The network currently encompasses over 175 stations that are located in economically important sites across the state. The data collected by the network have been the backbone for providing near real-time weather conditions and decision aids for producers. A critical application of the AWN has been for frost and freeze protection, but until recently no local forecasts or weather predictions have been provided.

In 2011, the Washington Tree Fruit Research Commission provided a one-year grant to explore how well a weather prediction model performed for Washington, especially the main fruit tree-growing region of the state. This grant allowed us to purchase a small High Performance Computer on which the Advanced Weather Research and Forecasting (WRF-ARW) has been implemented. Since implementation of the WRF model in 2012, hind-cast and real-time (operational) model predictions evaluated showed that WRF could be a significant informative tool in agricultural decision-making. A successful implementation of a high-resolution weather forecasting model with AgWeatherNet could have multiple outcomes, such as linking it to the many models and decision aids that are available on AgWeatherNet as well as for freeze forecasting.

The overall goal/motivation of this project was to evaluate the potential of implementing the WRF model as a tool for AgWeatherNet for weather and freeze predictions for Washington, specifically for regions where tree fruits are vital. Specific objectives included the following:

- To evaluate the performance of the WRF model for local conditions using the data and observations collected by AgWeatherNet.
- To develop a protocol for implementing the WRF model as a weather and freeze prediction tool for AgWeatherNet and associated decision aids.
- To develop freeze protection advisories for dissemination via the web, phone applications and other information technologies.

In 2011, the Washington Tree Fruit Research Commission provided a one-year grant to explore how well a weather prediction model performed for Washington, especially the main fruit tree-growing region of the state. That grant allowed us to purchase a small High Performance Computer (HPC) on which the Advanced Weather Research and Forecasting (WRF-ARW) has been implemented. As the model evaluation results were promising, further research was needed on the integration of the WRF model forecasting into other AgWeatherNet models and decision aids. It is this project that complimented and enhanced the previously started, but not completed work. This project supported further model tests, validations and evaluations, as well as the purchase of more compute nodes that grew the capacity of the HPC, (currently with 10 nodes, 320 processors), to complete the daily operational WRF prediction in which growers can get post-processed model results in time.

PROJECT APPROACH

As the custom of presentation of results to growers, the AgWeatherNet team presented one poster every year during the Annual Meeting of the Washington Association of Wine Grape Growers (WAWGG) since 2012. This year, it was held during the second week of February (9-11 Feb), 2016 in Kennewick and was attended by hundreds of growers, industry representatives and others interested in viticulture and enology. The AgWeatherNet team also had a booth during this meeting where the team displayed the AgWeatherNet hardware for monitoring local weather conditions and the AgWeatherNet portal with new features, including weather predictions.

•User survey on the use and application of the decision support systems on AgWeatherNet

The AgWeatherNet team provided questionnaires for in-person survey for the participants of the WAWGG annual meeting that was held in February 2016. While only 22 persons volunteered to complete the survey, weather (frost/freeze) prediction information and decision support tools came out as very important information that is needed by the specialty crop industry, especially tree fruit growers.

•Comparison of Performance of WRF Operational Model Predictions and Fox MtnRT Diagnostic Downscaling Model for the 2016 Growing Season for the Cherry, Apple and Wine Grape growing season

It was previously documented that the AgWeatherNet Advanced Weather Research and Forecasting (WRF-ARW) model was evaluated and validated in numerous times against AgWeatherNet observations and National Weather Service (NWS) National Digital Forecast Database (NDFD) outputs to infer its prediction ability of meteorological variables for the state of Washington. Those previous evaluations had shown that the model predicts more accurately over several AgWeatherNet stations with less topographic structural complexity as well as during the fair weather of a year. It was also proved that WRF forecasting accuracy drops as the region gets complex topographically and the weather conditions become so extreme, as the model generally showed underestimation of maxima and overestimation of minima temperatures over Washington State. Therefore, as the AgWeatherNet WRF data becomes available online for public use, the comparison against a diagnostic downscaling model called Fox MtnRT was imperative to further validate the products of WRF, particularly air temperature, which is critical meteorological variable for specialty crop growers for freeze/frost prediction. Fox MtnRT is a diagnostic weather forecasting model provided by Fox Weather, LLC (www.foxweather.com) and is widely used in the western agricultural regions of the US (Fox Weather, LLC, 2011).

It was also repeatedly reported that WRF has been undergone through model sensitivity analyses and evaluations in recognizing the optimal choice of combinations of physics options to predict near-surface meteorological elements, particularly air temperature for freeze/frost forecasting. To further cross-examine the performance of WRF against a widely used Fox MtnRT, 22 AgWeatherNet stations around the agricultural areas of eastern Washington were utilized in the statistical analyses for October 1-31 2015. However, only two stations are discussed in this final report (Detailed report can be request from the AgWeatherNet weather forecasting office). The two stations used in the analyses of air temperature forecast evaluations were: Roza (1,180ft) in Benton, and Wenatchee Heights (2,321ft) in Chelan counties. The WRF model requires several static and dynamic input variables to run. The Global Forecast System (GFS at 0.5-deg grid-resolution) analyses output provided “first guess” initial and boundary conditions (ICs and BCs) at 6-hr intervals for the daily WRF operational run. The Fox Weather, LLC runs the MtnRT diagnostic model by downscaling the NOAA’s WRF forecast at 7.46 mil to a horizontal scale of 0.93 mil for the Pacific Northwest regions (Fox Weather, LLC, 2011).

The October 1-31, 2015 operational WRF forecast with the first 24 hours outputs after the first eight hours were removed as a “spin-up” period were used in the comparison against the Fox MtnRT model first 24 hours results by adding the four-hours (0000-0300 PST; as their daily diagnostic simulation begins at 0400PST or 1200UTC) missing data from the previous day model outputs. Both WRF and MtnRT results were evaluated using the AgWeatherNet (www.weather.wsu.edu) observations. The AgWeatherNet temperature sensors are situated at 4.9ft, at which height the Fox MtnRT is provided and the WRF model provides temperatures at 6.6ft above ground level.

The WRF model, which started running operational once daily with WRF version 3.4 in August 2012, has now utilized an upgraded version 3.7.1. As of this reporting, there are more than four years of archived gridded data with the highest horizontal resolution of 1.9mi over Washington State and other coarser domains that cover the Pacific Northwest, which is expected to be helpful for further model evaluations and weather-related research and crop management studies. In this report, model results of air temperature are presented and compared against the Fox MtnRT model using the AgWeatherNet observations. The October 1-31, 2015 was used as an important period for the freeze/frost season over the state of Washington. Here, the daily WRF and Fox MtnRT 24-hour forecasts (after 8-hr ‘spin-up’ WRF mode period was removed, and 4-hours missing data from MtnRT was added from the previous day MtnRT output) were extracted from the October 2015 outputs to compare independently with AgWeatherNet observations. The analyses are discussed using time series plots and histograms, as shown below.

In the time-series plots (Fig. 2), observed temperatures are labeled by black line, while WRF control run with only the first eight-hour spin-up period removed in broken deep blue line, and the Fox MtnRT results after the first four-hours missing data were added from the previous day output are plotted in a broken deep red. Similar color- coding was also used to represent the same models’ variables for the histogram figures.

In general the model analyses persisted to show that WRF underestimated daytime temperature maxima and overestimated nighttime temperature minima. In this analysis, while the model reproduced temperatures more accurately, Roza station under predicted (negative bias) daytime maximum and over predicted (positive bias) nighttime minimum temperatures (See histograms in Fig. 2 below), while analysis results from Wenatchee Heights showed both daytime and nighttime temperature overestimation. Roza (Wenatchee Heights) station had daily average error (RMSE) of approximately 2.2oF (2.5 oF) and daily average bias (MB) of close to zero (1.8oF), as shown in the histograms below, respectively. Statistical analysis results for the Fox MtnRT model generally showed overestimation of observed temperatures over Roza (Wenatchee Heights) with the daily average error (RMSE) of 7.1oF (3.4oF) and daily average bias (MB) of 4.0oF (-2.4oF). In general, the WRF model predicted temperatures more accurately than the Fox MtnRT model for most of the 22 stations tested (all plots not shown).

In summary, while WRF generally predicted temperature values well for the first 15 stations, areas mostly located in the flat surface of the Columbia basin, the performance reduced slightly in the next four stations and significantly in the last three stations analyzed as the terrain structures and orographic complexities increase, in agreement with the previous sensitivity analysis reports. While further WRF comparisons against Fox MtnRT model is required using different weather cases, WRF performed much better than the Fox MtnRT for October 2015. This project report is another proof that the WRF model is a good forecasting tool that can help growers in decision-making.

The operational WRF modeling system provides predictions once daily since August 2012, using the Global Forecast System (GFS at 0.5-deg or ~35miles recently upgraded grid-resolution) analysis “first guess” data. The Fox MtnRT software is a diagnostic model owned privately by Fox Weather, LLC (2011) that downscales coarser horizontal resolution outputs from WRF to a higher resolution of 0.93mi. In general, the WRF run performed better in the prediction of air temperatures over the 22 stations evaluated. These stations were selected to represent locations with tree fruit (e.g. cherries, apples and grapes) growing areas of eastern Washington in the 2016 growing season. Therefore, with twice daily operational forecasting, the model can predict accurately and hence serve as an information tool in tree fruit and other specialty crops growers’ decision making.

•Integrate the output of the WRF model with the AgWeatherNet data base
The WRF model currently operates on a daily basis. The operational WRF model results that include 2-D color coded air temperature, wind speed and wind direction as well as precipitation of the Northwest Pacific regions and Washington state regions are shown on a daily basis on the AgWeatherNet website (weather.wsu.edu). The post-processed results also contain time-series plots of air temperature, dew point, wind speed and precipitation for three-day forecast, updated daily.

•Recommendations and ongoing projects
WRF used to run twice daily to perform two types of runs: first, the formal run initialized by GFS large-scale analyses and second, when the whole process is repeated by adding observations through observational nudging method. As the anticipated positive impact from the ingestion of observations was limited, the observations assisted model simulation was interrupted following the introduction of the latest WRF model version (v3.7.1) as operational. Future activities should include either to make the operational twice daily or extend the forecasting length from the current 3-day to maybe 10-day forecast so that growers will have extended weather and crop modeling forecasts for their decision-making. While the additions of compute nodes to the HPC didn’t help much in saving computational time, a fourth domain with horizontal resolution of 0.62mil can still be included to the WRF modeling configuration to help forecast overnight weather for freeze/frost prediction. It is to be noted that the WRF post-processing results are posted on the web (weather.wsu.edu) daily for growers & public use.

Interested people who accessed the online informative AgWeatherNet decision-making tools increased by more than 1,750 from October 1, 2014 to October 1, 2015 (Table 1). Although, the latest figure is not estimated, interested parties in AgWeatherNet program are growing. The information they seek and additional requests asked are tracked and are given particular attention for improvement.

GOALS AND OUTCOMES ACHIEVED

The overall goal of this project was to evaluate the potential of implementing the WRF model as a tool for AgWeatherNet for weather and freeze predictions for Washington, specifically for regions where tree fruits are vital. Therefore following objectives were achieved:

- Continuous evaluations of the performance of the WRF model for local conditions using the data and observations collected by AgWeatherNet was performed between 2012 – 2016 to infer that the WRF model can be used as agricultural informative tool in the state of Washington.
- The WRF model was later developed and implemented the WRF model as a weather and freeze prediction tool for AgWeatherNet and associated decision aids.
- The WRF model was developed to assist in the freeze protection advisories disseminated officially via the web starting October 2015. Further dissemination techniques such as phone applications and other information technologies are recommended for future use.

The current measurable outcome researched provides anticipated results for specialty crop growers and other researchers. However, further research work on the project would make the model results more reliable by increasing in time and space resolutions.

- Improve the hardware components of the High Performance Computer (HPC) system of AgWeatherNet for operation of the WRF model
    - Previously, two new compute nodes were added to the HPC to improve computational efficiency. The addition of the new nodes improved the time taken to complete the operational forecast. However, the hope of adding a high-resolution domain to the WRF model didn’t help in completing the forecast to

be available for use by growers and other end-users in a reasonable time. Although the HPC has added two new compute nodes, the test of the addition of the high-resolution fourth domain to the WRF model didn't help much in computational efficiency and therefore, the intended implementation of a fourth model was not made operational. Instead, the currently operational WRF completes the 3-day weather forecast in 2.5hrs from pre- to post-processing.

- Improve initialization of the WRF model using Global Circulation models and local AgWeatherNet observations
    - The addition of AgWeatherNet observations to the initialization was operational in the daily model forecast. However, further inspections and statistical analysis found that the WRF simulation drifted away from the synoptic input data once the AgWeatherNet observational data was not available into the future during model run. For this reason, the addition of observation for the operational forecast was interrupted.
- Compare WRF predictions with historical data from AgWeatherNet for the Cherry, the apple and the grape growing season
    - The project plans were performed successfully at their expected completion time and results were reported in their successive quarterly reports and is explained in the Project Approach section of this report.
- Integrate the output of the WRF model with the AgWeatherNet database
    - The post-processing is prepared and certain model results are currently posted in the AgWeatherNet webpage accessible to people who subscribed online.

The AgWeatherNet website's attraction for needy people is increased with time and the public online load will continue to grow as the decision making tools now include the WRF model (Table 2). Note that Google analytics does not currently include counts from automated data feeds (DAS, Tim Berk, Wine Map, MADIS, etc.). It is known that AgWeatherNet has a broad presence and impact beyond what is tracked by Google and the user counts, although currently there is little to no information about how frequently the AgWeatherNet data is viewed or used outside of the program's immediate realm of control.

BENEFICIARIES

Specialty crop growers, researchers and other interested bodies that have subscribed to the online free memberships have potentially benefited from this project. Also benefited are the project workers who have learned through research activities performed during the project work. A scientific survey is necessary to quantify the benefits/impacts people acquired by using this short-range operational weather forecast.

A survey is needed to clearly state the quantitative impact to the beneficiaries.

LESSONS LEARNED

The WRF prediction is a powerful tool for a short-range weather forecast. However, the prediction ability of the model weakens as the forecast target date is farther from the initialization time.

The model bias also increases as the complexity of the topography increases, due to poor geographical and other land/vegetation cover data.

The model requires a super computing system, computationally powerful enough, to be a real-time forecast information tool.

Availability of improved initial and boundary conditions data helps the model to forecast more accurately.

No unexpected outcomes or results affected the project.

Most goals were achieved. However, the goal and success of implementation of the operational model are only known when a survey to people with access to the AgWeatherNet website that provides the model predictions is performed and quantified.

ADDITIONAL INFORMATION

Match for Project: Cash match of $156,037 met in way of salaries and benefits for Gerrit Hoogenboom, Derek Weaver and Nic Loyd as well as unrecovered F&A from WSU.

Fig. 2. Diurnal time-series and their corresponding histogram plots of average temperatures from WRF and Fox MtnRT results plotted against observations averaged for October 1-31, 2015.

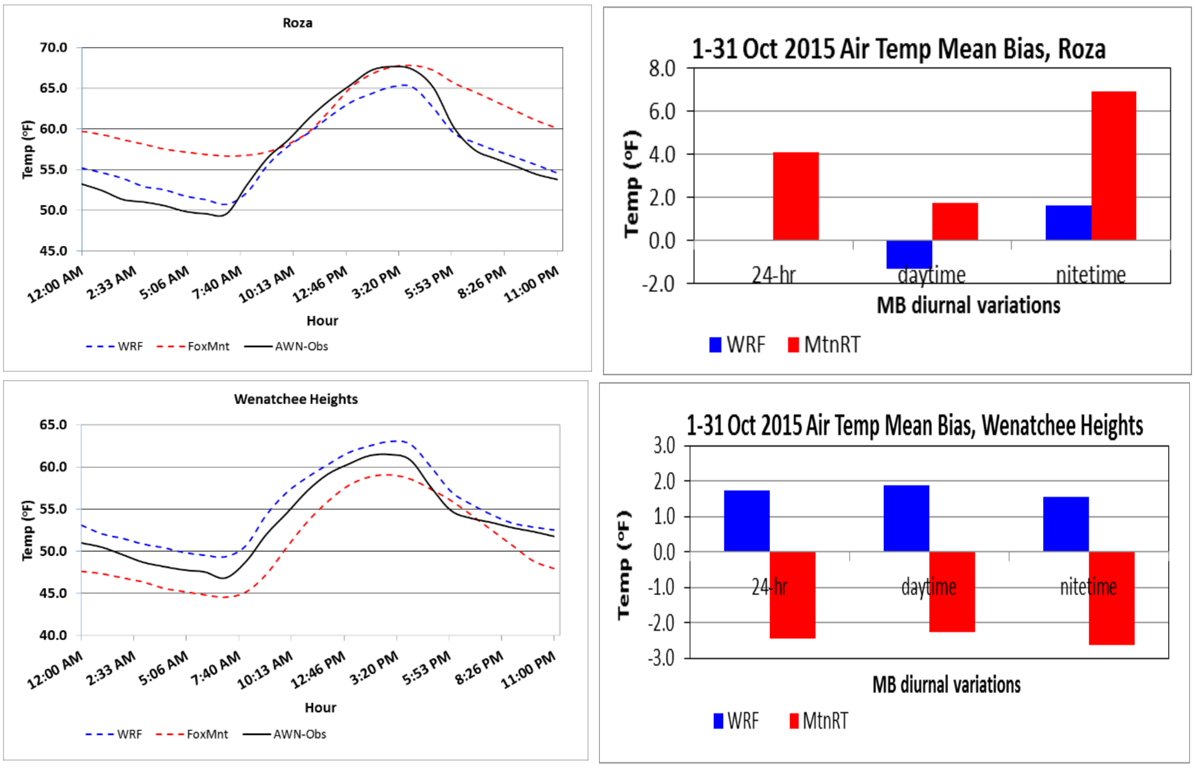

Table 1. Number of AgWeatherNet website subscribers and Facebook friends.

Date	AWN	Facebook Likes
Oct 1, 2012	6595	73
Oct 1, 2013	7608	299
Oct 1, 2014	8960	497
Oct 1, 2015	10,710	730
Oct 1, 2016		

Table 2. Google analytics of AgWeatherNet website as viewed by the public.

Google Analytics for weather.wsu.edu					
Date Range	Sessions	Users	Page Views	Pages/Session	Avg Session
Oct 1, 2012 – Sep 30, 2013	311,423	77,777	2,771,218	8.90	00:21:30
Oct 1, 2013 – Sep 30, 2014	922,777	225,108	8,232,522	8.92	00:18:16
*Oct 1, 2014 – Sep 30, 2015	429,054	118,066	4,162,152	9.70	00:10:55
*Oct 1, 2015 – Sep 30, 2016					

* - Changed the way that the page-views, etc., were counted to get a more realistic metric.

Project Title: Developing Camas as a dry-farmed specialty food crop

Partner Organization: Kwiáht: Center for the Historical Ecology of the Salish Sea

PROJECT SUMMARY

Although North American plants have been a major part of food production worldwide, little attention has been paid to "lost" and underutilized North American crop plants, including the "root foods" of the Pacific Northwest. Camas was the major staple crop in the Salish Sea and along much of the Pacific Coast of Canada and the United States prior to the introduction of the potato to this part of the world. Ethnographic records suggest that pre-Contact Coast Salish gardeners harvested over 138 metric tonnes of camas in the San Juans each year. Camas, the edible bulbs of "lilies" in the genus Camassia, are adaptable perennials that are currently only grown in gardens for their ornamental value. This was not always the case: prior to 1915, the great plant breeder Luther Burbank worked on developing camas as a food plant in California, as chronicled in the Chapter "The Camassia: Will it Supplant the Potato?" of Luther Burbank: His Methods and Discoveries and their Practical Application (1915). In a time of drought, climate change, and threats to native pollinating insects Kwiaht researchers identified the reintroduction of locally adapted flowering crops, such as camas (Camassia leichtlinii and C. quamash) as a unique opportunity for new, sustainable local food production.

Since the time when camas was the primary staple crop grown in the San Juans, the landscapes in which it was cultivated have been irreversibly altered through the introduction of non-native grasses, livestock grazing, and residential development. For this reason, Kwiaht researchers focused on developing methods for cultivating food camas in modern gardens and farms rather than recreating pre-Contact agricultural conditions.

Because camas has not been grown as a food crop in over 200 years, this project also needed to develop a market for food camas and introduce both consumers and producers to the food value of camas. Convincing farmers and gardeners to produce a crop with no market was not a feasible option. At the same time, Kwiaht's partners at the Skagit River Systems Co-op helped to identify the existing demand for a supply of food camas: traditional food and ceremonial use by Tribal Communities.

The overall aim of this project was to develop methods for producing camas as dry farmed food crop in the San Juans and western Washington, build consumer interest and demand for food camas and value-added camas products, work with value-added producers and outlets to bring camas products to market, and to ensure that Tribal members and food programs have sufficient access to food camas.

Farmers and gardeners worldwide are currently facing the challenges of a changing climate, the globalization of plant diseases, and concerns about pollinator health. In the Pacific Northwest and the Salish Sea region much of the challenge is facing longer summer droughts and an increasing amount of overall annual rainfall occurring during severe weather events. At the same time the interest and demand for local food is at an all-time high, and local market gardeners are interested in producing unique, local, heritage foods that grow well in their region and appeal to consumers. Uniquely adapted to the climate of the Pacific Northwest, and able to withstand long summer droughts and very wet winters, perennial native camas bulbs are a crop that meets these needs. If allowed to flower in production beds, camas also provides food and habitat for native bees and pollinating flies, and can attract these highly effective pollinators to the surrounding cultivated areas as well, providing pollinator services beyond the camas bed itself.

At the same time, wild populations of camas are increasingly threatened by development, non-native invasive species, and, particularly in the Salish Sea region's coastal meadows, by rising sea levels and increased storminess. Bringing camas cultivation into farms and gardens is important to preserving the genetic diversity and genetic resources of this native crop plant.

Now is also a time of cultural revitalization among the Coast Salish in Washington State and British Columbia, leading to the potential for increased demand for food camas for ceremonial and cultural use. Wild harvesting cannot meet this demand, and it is the right time to support and promote food camas cultivation by emerging Tribal farmers and gardeners.

This project did not build on any previously funded SCBGP project.

PROJECT APPROACH

During this project Kwiaht researchers tested camas cultivation methods in research garden plots on Lopez Island and on the Swinomish Reservation. Beds of Camassia leichtlinii and C. quamash were experimented with at different planting densities, and with the application of straw mulch. Additional C. leichtlinii beds were cultivated with the addition of fish bone meal fertilizer and straw mulch, straw mulch alone, and using a weed torch for fire weeding. During the 2016 growing season, Kwiaht gardeners removed flowering stalks from a third of the bulbs before seed-set. Kwiaht gardeners compared productivity, the proportion of bulbs that formed contractile roots, and the proportion of bulbs that grew bulblets under each treatment. The formation of contractile roots reduces productivity and harvest results led to the conclusion that contractile root development can be significantly reduced by applying straw mulch, and that flowering stalk removal increases productivity when combined with mulching. Bulbs that produced bulblets were recorded in nearly every treatment, allowing Kwiaht gardeners to begin propagating more productive camas varieties.

Kwiaht researchers provided camas cultivation information to local and regional farmers and gardeners through direct targeted e-mail contact; outreach at the 2014 Vancouver Island Traditional Foods Conference; presentations at the 2015 and 2016 San Juan Islands Agricultural Summits; camas tastings at the Agricultural Summit, Kwiaht's research garden on Lopez, the Orcas Island Food Coop, and Blossom Organic Grocery; and through the First Annual Camas Festival in 2016. At least 39 farmers and gardeners were supplied with camas seed and/or bulbs to cultivate. Kwiaht researchers distributed over 6,000 camas seed to 20 farmers and gardeners (16 in the San Juans and 4 in neighboring Western Washington) and distributed camas bulbs to at least 29 gardeners.

Kwiaht's botanist and ecologist worked with elementary students at Friday Harbor Elementary, Lopez Island School, and Orcas Island School to plant camas plots in their school gardens. Students received lessons on the history of camas cultivation, food camas chemistry, and camas pollinator ecology. The Orcas Farm to Classroom program (with 180 elementary students) scheduled a lesson based on harvesting, preparing, and eating the camas they grew, while the Friday Harbor and Lopez classes plan to continue making observations of pollinator visits to their camas plots in 2017.

Kwiaht researchers conducted outreach to value-added food producers to gauge and build interest in value-added camas product production. Barn Owl Bakery proposed camas scones, Mirabelle Ice-Cream expressed interest in trying in ice cream, and Vortex Juice Bar and Cafe planted local camas on Lopez for use in their products.

Kwiaht researchers discussed camas based dishes with local chefs and cooks, working to build interest from local restaurants for camas based dishes. Discussions were held with cooks from the Bay Cafe, Bucky's Island Grill, Vortex Juice Bar and Cafe, the Love Dog, the Doe Bay Cafe. Based on these discussions most, if not all, of these venues would trial a camas based dish when local production has a consistent supply of food camas available. Kwiaht is planning on scheduling individual camas tastings with interested chefs and cooks as a next step in getting camas on the plates of local restaurant goers.

For camas tasting and increasing interest in food camas, Kwiaht's botanist tested and documented using a slow cooker to cook camas until the inulins are fully broken down into fructose. Using this method Kwiaht served at least 300 people prepared camas at tastings at the 2016 San Juan Islands Agricultural Summit, a camas tasting at Kwiaht's Lopez camas garden, and tastings at the Orcas Island Food Co-op and Blossom Organic Grocery. At each tasting Kwiaht collected feedback on the camas samples, offered information on camas cultivation and preparation, and distributed camas bulbs to interested growers. The tasting at Kwiaht's Lopez camas garden was part of Washington State's local history month, and advertised statewide; attendees included students and instructors from the Northwest Indian College. For that tasting Kwiaht's botanist developed a sweet camas spread, a chocolate-almond-coconut camas spread, and a smoked salmon and camas spread. Kwiaht's ecologist also served prepared camas to 80 attendees at his Roads Scholar Native History lectures for Skagit Valley College.

In 2016 Kwiaht held the First Annual Camas Festival which included seven unique camas based dished developed by Kwiaht's botanist: sweet onion camas salsa, camas kanten, camas panna cotta, camas albondigas (meatballs), sweet camas spread, chocolate camas spread, camas and honey ice cream. Kwiaht's research gardeners also served a camas cheesecake. The camas dishes were served alongside traditionally cooked sockeye salmon and fry bread prepared by Rosie Cayou James and William Bailey of Salish Tacos.
Working with artist and designer Camilla Loyd, Kwiaht's botanist tested and refined recipes for the most popular dishes served at the festival and put them together in an illustrated online cookbook that will be available on Kwiaht's website.

Throughout the project Kwiaht's gardeners and botanist collected and preserved leaf tissue samples from camas for genotyping. Kwiaht's botanist initially genotyped 40 camas samples at up to 6 microsatellite loci. The genotyping work overlapped with Kwiaht acquiring a new genetic sequencer, which expanded capacity, but also required that the initial genotypes be redone for consistency on the new instrument. The camas genotyped so far makes up the beginning of a baseline of genotypes of camas populations from the San Juan Islands, which can be used to characterize particularly productive, nutritious, or flavorful varieties. Students and Lopez High School assisted with genotyping work.

Kwiaht's botanist contacted the food programs at Lummi and at the Small Tribes of Western Washington (which provides the food program for many Tribes in the State including Samish, Swinomish, Tulalip, and Upper Skagit) to offer them camas bulbs for distribution. While neither of these programs requested camas during this project, Kwiaht's botanist and gardeners supplied camas bulbs for growing to the Samish Community Garden, and to gardeners who are Tribal Members at Samish and Upper Skagit. Kwiaht's botanist also supplied cooked bulbs to the Swinomish Tribal Council for a traditional meal served during a council meeting, and to the Samish and Stilliguamish Canoe Families during a Leave No Trace training event on Lopez Island.

The Skagit River Systems Cooperative (a collaboration of the Swinomish and Upper Skagit Tribes) provided Kwiaht with the research garden on the Swinomish Reservation during this project. In 2013 they plowed approximately 2 acres and donated over 5,000 2-year old Camassia quamash bulbs. SRSC also donated approximately 20 hours of labor assisting with planting camas bulbs in 2013. Additional Tribal partnerships include the Samish Community Garden planting food camas bulbs in 2015, Sam Barr with the Samish and Stilliguamish Canoe Families helping to serve camas to Tribal youth during a Leave No Trace training on Lopez in 2016, and Jessica Gigot at the Northwest Indian College and Myk Heidt at the Swinomish Community Health Program coordinating having Kwiaht supply prepared camas for a traditional meal served during a Swinomish Tribal Council Meeting in 2016. The Toquaht Nation in British Columbia hosted the 7th Annual Vancouver Island Traditional Food Conference and funded travel by Kwiaht's botanist to attend and present on this project.

The farmers and gardeners who tried growing food camas donated a great deal of space and time to this project. 39 farmers and gardeners tried growing camas during this project, donating their garden space and time. These gardeners included both small scale kitchen gardeners, and large scale market gardeners including Helen's Farm on Lopez Island, Blue Moon Farm on Waldron, Frog Tree Farm on Orcas, and Mamma Bird Farm on San Juan.

Island Schools were an important partner in this project, hosting camas beds in their school gardens, and with approximately 300 students participating in designing camas beds, planting bulbs, observing pollinators, and sampling prepared camas. In addition Lopez School hosted bulbs in their school atrium and hosted Kwiaht's genetics lab throughout the project.

Orcas Food Coop and Blossom Organic Grocery on Lopez hosted camas tastings making a table available and encouraging their customers to sample prepared camas and take home information on food camas.

The San Juan County Agricultural Resources Committee invited Kwiaht botanist to present at the San Juan Islands Agricultural Summit in 2015 and 2016, waiving the registration fee (a value of $50 each year). Kwiaht was supported in developing camas preparation methods by WSU County Extension and by the Taproot: The Lopez Island Community Kitchen.

Because camas is such a unique crop, none of the activities in this project benefitted any other commodities

GOALS AND OUTCOMES ACHIEVED

To achieve the goal of at least 30 market farmers and gardeners growing food camas, Kwiaht contacted farmers and gardeners, held outreach events, and supplied camas seed and bulbs. Targeted outreach included e-mails to 33 farmers and gardeners in the San Juans and western Washington, and presentations at the 2014 Vancouver Island Traditional Food Conference and the 2015 and 2016 San Juan Islands Agricultural Summits. Kwiaht's botanist and ecologist also distributed camas bulbs during camas tastings and included information about camas cultivation during presentations on Native history for the Roads Scholar programs at Skagit Valley College.

Kwiaht worked towards the goal developing a market for value-added camas products through three group of activities: outreach to value-added producers, outreach to specialty markets, and camas recipe development and tastings. Camas tastings gave market owners and their customers the opportunity to sample prepared camas and to demonstrate its acceptance by customers. Both of these markets, as well as the San Juan Island Food Co-op have committed to stocking prepared camas and value-added camas products as soon as a consistent supply is available. Most of the value-added producers reached also sell their products at farmers' markets, including the Lopez, Friday Harbor, and Orcas Farmers' Markets. Product ideas were developed with Barn Owl Bakery (camas scones), Mirabelle Ice Cream (camas ice cream), Kraut Pleasers (camas pickles). Value-added producers and potential customers were also reached through the First Annual Camas Festival, where they were able to sample example camas dishes prepared by Kwiaht's botanist alongside traditionally grilled sockeye salmon and fry bread.

Progress on the goal of getting camas based dishes served in local restaurants was made by direct outreach to local restaurant owners, chefs, and cooks. None of the cooks and chefs approached had eaten camas before, and needed information on the flavors and textures and ideas for how camas could be included in recipes. Kwiaht's camas cookbook is also aimed at chefs and cooks to give them an idea of how camas can be utilized in the kitchen.

Kwiaht achieved its goal of making food camas available to the Tribal food programs at the 5 US Tribes with historical connections to the islands by reaching out to food programs serving all 5 communities in 2016 with an offer of prepared or living bulbs. While Lummi and the Small Tribes Organization of western Washington (which serves 17 Tribal communities including Tulalip, Samish, and Upper Skagit) did not request any bulbs, Kwiaht provided prepared bulbs for a traditional food meal served to the Swinomish Tribal Council. Through outreach, particularly through the 2016 Camas Festival, Kwiaht was also able to provide living bulbs to the community garden at the Samish Tribe, and to individual Tribal gardeners at Samish and Upper Skagit (one gardener from each community), partially achieving the goal of having at least one gardener from each community growing food camas. Targeted outreach at the planned 2017 Camas Festival is likely to reach gardeners at Swinomish, Lummi, and Tulalip as well.

Achievement of the Expected Measurable Outcomes was not anticipated to be long term, but during the project it became clear that the goals of bringing camas to market were dependent on first building reliable food camas production, and are indeed longer term goals. Kwiaht researchers laid the basis for value-added camas products being sold in three specialty markets, and production of value-added camas products by producers who sell at three farmers' markets. Outreach to restaurants laid the basis for camas based dishes to be served to at least four restaurants in the San Juans. Based on the feedback from value-added producers, specialty markets, and restaurant owners and cooks Kwiaht anticipates that interest in food camas will continue to grow rapidly, such that as soon as a reliable production and processing framework exists the Outcomes of 88% of Farmers' Markets in San Juan, Skagit, and Whatcom County and camas based dishes served in 50% of San Juan County restaurants will be achieved.

This project built the interest and knowledge to achieve the goals that were established at the outset. The goal of building a network of camas growers was accomplished, and the research conducted during the project on best camas cultivation techniques is helping these growers. During the course of the project Kwiaht researchers identified initial camas processing (cooking to convert inulins into fructose) as a separate necessary step to food camas production and value-added product development. This step created a barrier between camas growers and food camas sales. Kwiaht researchers developed small scale processing methods and started conversations with the county extension office to begin making progress on collective camas processing. The need to achieve a consistent supply of food camas and coordinated processing meant that the goals of commercial camas availability were not achieved during the project period. However significant progress was made on these goals through camas tastings, and the First Annual Camas Festival, all of which demonstrated to specialty markets and value-added producers the versatility of camas, and its attractiveness and acceptance by their customers. Although it was not a goal at the outset of the project, an important accomplishment was having around 500 people (including students) sample food camas during this project, and having prepared camas available in two specialty markets (as samples, with commitments to stock it once a consistent supply is available).

At the start of this project Kwiaht's botanist contacted 33 farmers and gardeners in the San Juan Islands and western Washington and was unable to find any farmers or gardeners growing food camas. Over the course of this project additional farmers and gardeners were reached through outreach events, and none of them were growing food camas prior to receiving seed or bulbs as part of this project. Through seed and bulb distribution, as well as outreach on camas cultivation and preparation methods, this project directly led to at least 39 farmers and gardeners in the San Juans and neighboring western Washington growing food camas by 2016. Based on the demand for bulbs that Kwiaht researchers observed during outreach events, this number will continue to rise as long as food camas outreach events occur, and include the opportunity for farmers and gardeners to receive bulbs at these events.

With no sources of food camas, there were also no groceries, co-ops, or farmers markets offering food camas for sale at the beginning of this project. Kwiaht researchers visited farmers markets on Lopez, Orcas, and Friday Harbor, as well as the Skagit Valley Co-op, Orcas Food Co-op, and Blossom Organic Grocery, none of which had any food camas products for sale. To achieve the goal of having food camas and value-added camas products available at these venues Kwiaht researchers made contact with value-added food producers, and with the Friday Harbor and Orcas Food Co-ops and with Blossom Organic Grocery on Lopez Island. Prepared camas tastings were held at the Orcas Food Co-op and Blossom Grocery in 2016 and all three retailers have agreed to carry prepared food camas once it is available for them to stock. Throughout this project Kwiaht researchers conducted outreach to value-added food producers in the San Juan Islands, and worked to build interest in camas-based value-added food products. Camas tastings, and particularly trialing camas based dishes at a tasting and at the First Annual Camas Festival proved to be critical to gaining interest by value-added producers, since none of the producers contacted by Kwiaht's botanist had ever tasted camas prior to the tastings held during this project. Through the tastings, and the interest generated, Kwiaht was able to build interest from value-added producers that sell products at the Lopez, Orcas, and Friday Harbor farmers markets. Camas was served in 2 specialty markets in the San Juans (achieving that portion of the Expected Measurable Outcome) and once a steady supply of locally grown food camas, and of cooked camas is available to these producers the Outcome of having camas in 88% of farmers markets in Skagit, Whatcom and San Juan County is likely to be rapidly achieved.

At the start of this project none of the restaurants in the San Juan Islands were offering any camas based dishes on their menus. Through the project contact was made with restaurant owners, chefs, and cooks at the Bay Cafe, Love Dog, Bucky's Island Grill, Vortex Juice Bar and Cafe, and the Doe Bay Cafe all of whom were interested in trialing camas based dishes once a steady supply of food camas is available in the islands. The owner of Vortex Juice Bar and Cafe planted a bed of local camas to begin producing her own food camas. These commitments to trial camas based dishes represent 40% of the restaurants on Lopez Island and around 10% of the restaurants in San Juan County.

An important goal of this project was to ensure that Tribal food programs and gardeners had access to food camas. None of the Tribal food programs contacted by Kwiaht's botanist (Lummi, Samish, Swinomish, and the Small Tribes of western Washington which serves many Tribal communities including Tulalip, Upper Skagit, Samish, and Swinomish) had or were providing food camas at the start of this project. In 2016 Kwiaht offered food camas to all of these programs. Kwiaht's botanist also supplied prepared camas to the Swinomish Tribal Council, camas bulbs for planting to the Samish Community Garden, and bulbs to gardeners who are enrolled at Samish and Upper Skagit. Two Swinomish Tribal members participated in research gardening during this project. The camas grown on the Swinomish Reservation is available to Swinomish Tribal gardeners and to the Swinomish Branch of the Northwest Indian College. The goal of making food camas available to Tribal food programs was fully achieved, and the goal of having Tribal gardeners growing camas at the five communities with historical ties to the San Juans was 40% achieved (not including the camas garden at Swinomish, as it continued to be maintained by Kwiaht's research gardeners). Targeted outreach through tastings and the Second Annual Camas Festival (in 2017) should allow Kwiaht to reach more Tribal gardeners.

BENEFICIARIES

Farmers and gardeners in the San Juan Islands and western Washington, including Tribal members at Samish and Upper Skagit who received camas seeds and/or bulbs and cultivation information benefited from this project.

Tribal partners, including the Swinomish Tribe, the Samish Community Garden, the Samish Canoe Family and the Stilliguamish Canoe family benefited from receiving bulbs or prepared camas during this project.

Specialty markets on Lopez and Orcas (the Orcas Food Co-op and Blossom Organic Grocery) benefited from camas tastings held at their stores during this project.

Friday Harbor, Orcas, and Lopez Schools benefited from including this project in their science or farm to classroom curriculum, as well as by including camas in their school gardens.

Thirty-nine farmers and gardeners received camas seeds and/or bulbs during this project, all of whom were still growing camas when contacted at the end of the project in 2016. Kwiaht is working to ensure that any camas they produce has a waiting market, either by a processing collective, value-added food producers, restaurants or through a specialty market or farmers market.

Partners at Swinomish have 25 beds of 90-180 bulbs of camas each planted at the research garden on the Reservation, and received enough prepared bulbs for a meal served to their Tribal Council in 2016. Approximately 100 bulbs were provided to the Samish Community Garden. Two gardeners who are Tribal members at Samish and Upper Skagit, respectively received approximately 50 bulbs each. The Samish and Stilliguamish Canoe Family youth (8 youth and 3 instructors) received a camas meal, and instructions on cooking camas.

Approximately 100 customers at the Orcas Food Co-op and 100 customers at Blossom Organic Grocery sampled camas during tastings, and Kwiaht advertised these tastings to over 2000 people through social media and websites. While many of the tasters were customers who came to the store for regular shopping, some of the tasters visited these markets specifically to come to the tastings (approximately 20% based on feedback).

Friday Harbor, Lopez, and Orcas schools received 36-200 camas bulbs each for their school gardens and science enrichment for students by Kwiaht researchers (botanist and ecologist). Over 350 students participated between these three schools, receiving approximately 25 classroom hours of enrichment. Approximately 180 students at Orcas elementary also sampled a camas based dish prepared by Kwiaht's botanist.

LESSONS LEARNED

Embarking on bringing a “new” food crop to the market provided many lessons for Kwiaht's staff during this project. Positive lessons included discovering that there is an existing demand for food camas for Tribal ceremonial and cultural use, which provides an added incentive for supporting new Tribal farmers and gardeners in getting into camas growing. This demand was identified by project partners at the Skagit River Systems Co-operative (a collaboration of Swinomish and Upper Skagit). Kwiaht's research gardeners also learned that contractile root growth can very effectively be reduced by mulching bulbs, even if they are planted close to the surface, and preliminary results show that reducing contractile root growth increases productivity, and ease of harvest. Research gardeners also experimented with removing flowering stalks from camas, and found that when combined with mulching, removing flowering stalks increases productivity, and makes summer harvesting easier (cut bulbs do not have hard flowering stalks through the middle of the bulb). Through preparing camas for the Swinomish Tribal Council in May, Kwiaht's botanist learned that camas harvested and cooked during the flowering period is practically indistinguishable as food from camas harvested when dormant, though it is slightly harder to process due to the flowering stalks (which can be removed prior to flowering as stated above).

In developing camas preparation methods, Kwiaht's botanist learned that sweet, digestible camas can be consistently produced using a slow cooker, and that cooked bulbs can be dehydrated for storage and retain their quality when re-hydrated. Camas tastings provided the opportunity for Kwiaht researchers to learn that nearly everyone who sampled plain food camas found it pleasing (98% of the tasters who gave feedback). Based on wild food books and websites Kwiaht's researchers had expected cooked camas to be more unusual and perhaps something of an “acquired taste”, which was not at all the lesson from tastings held throughout the San Juan Islands.

The First Annual Camas Festival was an opportunity for Kwiaht researchers to find out whether camas-based dishes and potential camas value-added products were accessible to consumers. Of the eight camas based dishes presented at the First Annual Camas Festival, seven were very well liked (camas kanten or agar was rejected based on texture), including both sweet and savory dishes, and in combination with grilled sockeye salmon and Coast Salish style fry bread. These dishes created an opportunity for Kwiaht's botanist and researchers to explore the types of camas dishes and value-added products that will appeal to consumers and restaurant goers, and to build a cook book of example dishes to expose more people to food camas and camas based dishes.

When Kwiaht's botanist followed up with farmers and gardeners who grew food camas during this project, she found that while their growing experiences were mostly positive (particularly for those that started with bulbs rather than seeds) that they were reluctant to harvest the bulbs, and unenthusiastic about undertaking the long cooking that prepared camas requires. Based on the identification of camas processing as a bottleneck in food camas production, Kwiaht's botanist was able to explore options for organizing/processing camas from many small producers, and started discussions with County Extension and Taproot (Lopez' community kitchen) to develop processing capacity.

Researchers faced challenges during this project as well, including learning that some of the proposed activities would not lead as quickly to the expected outcomes as hoped. For example attempting to grow harvestable camas from seed during the period of the project was impractical. Small bulbs were also found to be much more vulnerable to competition from weeds during summer drought, and weed control for seedling and small camas survival was found to be critical but very challenging. In order to produce eating sized camas, Kwiaht's gardeners had to purchase restoration stock bulbs. Once harvestable bulbs were available Kwiaht researchers were able to make much more significant progress on building a value added market, but the delay between working on cultivation methods and being able to provide prepared camas to consumers, value-added producers and restaurateurs meant that this project came to completion while food camas products and production methods are still in development and not yet available commercially.

Identifying camas processing as a bottleneck in the market for food camas is an important lesson, but one that delays the release of camas into the market until processing can be coordinated and producers organized. While camas tastings showed that prepared camas is well liked by consumers, researchers learned that very few consumers had heard of camas, or had any conception of how prepared camas would taste. Before camas products will have a wide market, more tastings and education needs to take place so that consumers will be interested in purchasing products.

Based on this project Kwiaht has developed a strategy for developing and introducing additional “lost” Salish Sea crops to producers and consumers, and has received private funding (from the Mills Davis Foundation) to begin work on developing production and a market for 10 more native food crops. Because of Kwiaht's role in testing camas processing, this project resulted in camas being available to Tribal youth participating in the Samish and Stilliguamish Canoe Families during a visit to Lopez. This project has resulted in Kwiaht working with county extension and Taproot to develop a camas processing co-operative that can purchase, process, and distribute camas from local farmers and gardeners.

Kwiaht researchers learned that when bringing a “new” food crop to market it takes time to build interest and experience in the new food, and that a lot of time needs to be devoted to sharing methods and ideas for preparation and providing samples for both consumers and producers to try. Value-added producers and restaurateurs need sufficient time to learn about an ingredient before they want to try it out on their customers. Even in the San Juan Islands many of the people who tried camas at Kwiaht's tastings had never heard of camas as a crop, and had no idea what kind of a plant the new food came from. Even tasters who were aware of camas' edibility had no idea what it was going to taste like, and often were (pleasantly) surprised by the sweet flavor. The initial phases of introducing a new crop require not just education about growing methods and supplementing production, but also extensive outreach and opportunities for producers and customers to try the new crop, and ways in which it can be utilized.

ADDITIONAL INFORMATION

Match expended on this project totaled: $109,006 ($15,500 cash and $93,506 in kind)

Kwiaht provided in-kind match of genotyping equipment (valued at $66,038) and received a cash donation of $15,000 from an Orcas Island donor to purchase a capillary sequencer. This equipment was used in building a baseline of camas genotypes with which productive or unique strains can be characterized, and which supports the breeding of food camas varieties. 20% of the annual lease of Kwiaht's office on Lopez was included as match ($2,851) this office was used for coordination and outreach on Lopez. The Skagit River Systems Cooperative donated $2,500 worth of Camassia quamash bulbs and $620 worth of labor planting to this project. Kwiaht provided $1000 worth of Camassia leichtlinii bulbs and $320 worth of C. leichtlinii seed. Ryan Drum of Waldron Island donated 1,163 small camas bulbs and 2lbs of camas seed (for a value of $2470). Bulbs were used for researching effective camas cultivation methods in the gardens at Swinomish and on Lopez Island, seeds were distributed to local farmers and gardeners and used for producing camas in the research gardens. Kwiaht provided use of chemistry supplies and equipment for soil testing (valued at $4,707) for testing nutrients and salinity at the camas gardens. The San Juan Agricultural Resources Committee waived the registration fee for Kwiaht's botanist to participate in the 2015 and 2016 San Juan Island Agricultural Summits ($50 each summit, for a total of $100), and the Toquaht Nation paid for Kwiaht's botanist to attend the 7th Annual Vancouver Island Traditional Food Conference ($500 cash). Kwiaht apprentices volunteered 30 hours towards this project (valued at $25/hr for a total of $750). Students at Friday Harbor, Lopez, and Orcas Schools donated approximately 700 hours to this project in planting and maintaining camas gardens and in observing pollinators (valued at $17/hr for a total value of $11,900). Whispers of Nature donated the use of their herb garden and labyrinth for the First Annual Camas Festival (valued at $200 for the afternoon), and Julie Galbraith donated alder firewood for the fish cooking at the festival (valued at $50).

Camassia:

Camas is a perennial bulb related to Agave with blue or (more rarely) white flowers, blooming between April and mid June. Two species of camas are native to the San Juan archipelago: blue camas (*Camassia quamash)* and great camas (*Camassia leichtlinii*). After flowering and producing seed camas goes dormant until winter when leaf growth begins, even under snow! Camas habitat includes rocky open bluffs or balds as well as open meadows.

Ethnobotany:

Camas was a vital food crop for the native Coast Salish people who inhabited these islands. The bulbs were dug in large quantities and pit roasted until they became sweet. Because it was carbohydrate rich, camas was highly prized and widely traded throughout the region. Coast Salish families traditionally cared for and cultivated large camas patches; cultivation increases bulb size, productivity and range. Traditional management utilized a combination of transplantation, weeding, hoeing and burning.

Management and Care:

Camas can be propagated from seeds planted in the fall or stratified by mixing with moist, sterile media such as coir and chilled in the fridge for 60+ days before planting outside. Seeds should be lightly covered. First-year seedlings have very small grass-like leaves; they will grow contractile roots that pull them down into the soil.

Bulbs can also be purchased or requested from Kwiaht's camas growers network. Bulbs should be planted in the fall and winter.

Camas is very tolerant of different *soil* types and can tolerate both drought and periodic inundation. Moist, loose soil, rich in inorganic matter is likely to produce larger bulbs.

To produce the largest bulbs, with few contractile roots: plant bulbs between August and December in a narrow trench approximately 1-2 inches deeper than your largest bulbs, adding approximately 1 tablespoon of bone meal or fish bone meal if desired to each foot of trench and mixing into the soil at the bottom before planting the bulbs. Cover with soil and mulch with at least 2 inches of straw.

Harvesting Camas

When flowering stalks form in spring remove from any bulbs you wish to harvest that year (they can be removed as soon as they form, or while the plants are in full flower). Bulbs may be harvested for cooking at anytime, but are easiest to harvest and largest once all the leaves are brown. Return small bulbs and any bulblets formed by larger bulbs to the camas bed.

If you join our growers network we will keep you up to date with our research results as well as work to connect producers with markets and makers of value-added products.

Contractile roots

For more information or to join our camas growers network contact

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Our thanks also to Brook Brouwer, the Swinomish Tribe, Skagit River Systems Cooperative, Linda and David Hudson and Liz and Jeff Malinoff.

Cooking Camas:

Camas is inedible until properly cooked! It is rich in inulins: short chains of fruit sugar that humans lack the enzymes to digest. Long, moist cooking breaks the inulins down into fructose, a simple sugar that is easy to digest. The traditional method for cooking camas is by pit roasting large quantities of camas for two days.

Smaller quantities of camas can be cooked in a crock pot: clean bulbs (saving the root end of replanting). Line a crock pot or slow well with washed thimble berry leaves, soaked corn husks, or crumpled parchment paper. Add water to cover the leaves on the bottom (around a cup). Line a well in the middle with parchment paper and fill with cleaned bulbs (a full pot will cook more evenly), fold the paper over the top the bulbs, and cook on low for 48 hours, adding more water as needed (every 12 hours or so).

After 48 hours the bulbs will be soft and brown and can be eaten as is, added to recipes or frozen or dried for storage, freshly cooked they are quite perishable and will keep for only a few days in the fridge.

Chopping bulbs before drying makes them easier to re-hydrate and use in recipes. Dry chopped bulbs until fully dry in a dehydrator. Bulbs may be frozen whole with no loss of quality. To re-hydrate dried camas: cover with boiling water .

Cooked camas is mildly sweet and slightly nutty. For recipe ideas see the cookbook on Kwiaht's website.

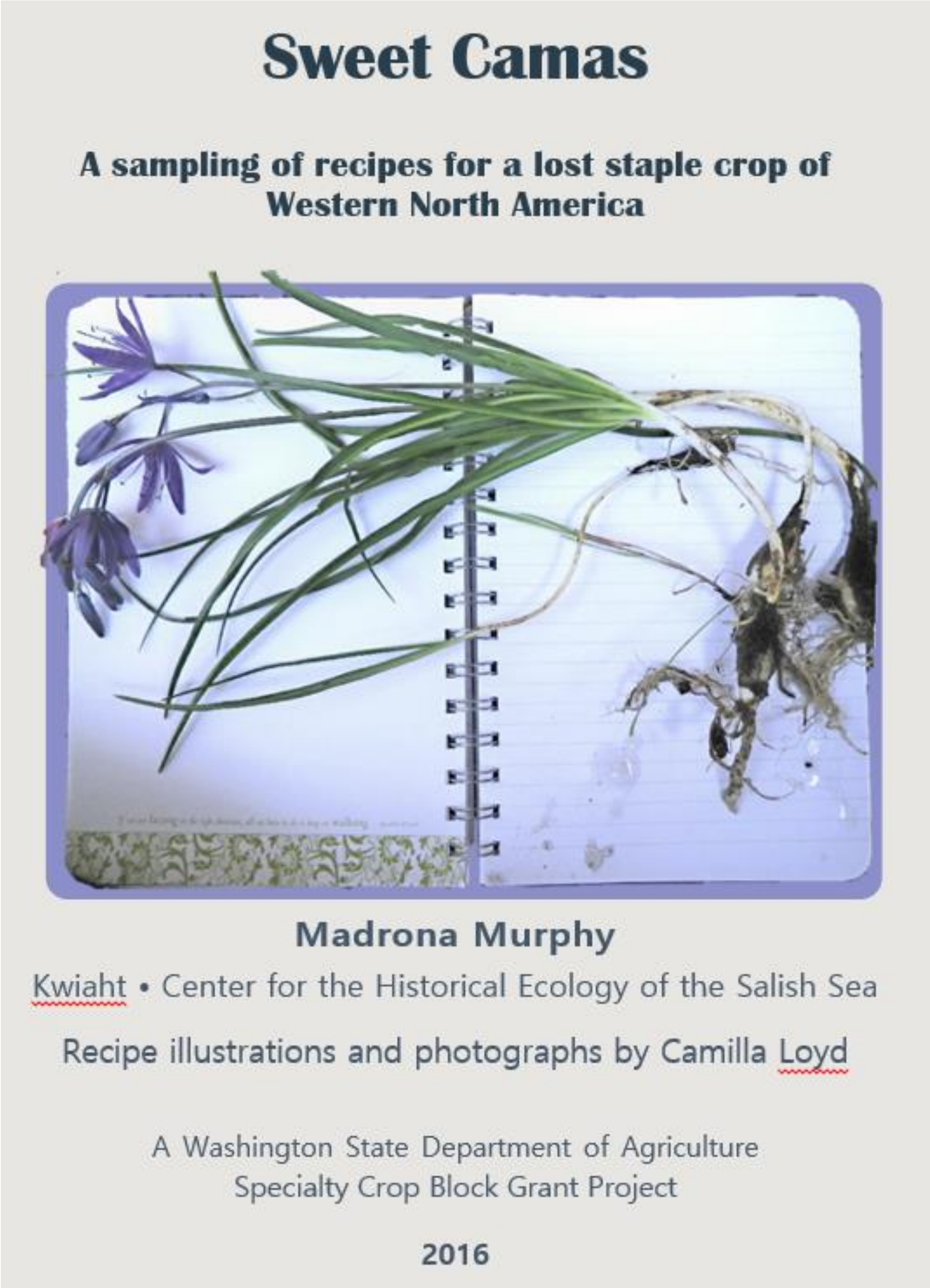
Growing a Local Market

Pre-Contact Coast Salish farmers are estimated to have produced and harvested over 138 tons of camas bulbs in the San Juans each year! We are enthusiastic about recovering a small amount of that local productivity. Kwiaht is working on developing camas as a dry-farmed specialty food crop in the San Juans, and that includes building a market for camas bulbs, cooked camas and value-added camas products. If you are interested in trying food camas, as a grower, produce market, restaurant, consumer or producer of value-added products, we'd be delighted to include you in the project and to insure that our work supports your ideas and interests. For more information contact us at kwiaht@gmail.com.

We are also dedicated to preserving the unique genetic diversity of camas in the San Juans; our food camas seed sources are regional and intended only for farm and garden use. If your interest is restoration rather than, or in addition to food production, we are always happy to work with you to source locally appropriate seed. Kwiaht researchers are also using genetic tools to investigate this local diversity and identify promising local varieties.

Growing Food Camas

Camas (*Camassia spp.*) was the most important plant food grown by native Coast Salish in the Salish Sea and San Juan Islands. As a drought tolerant, disease resistant native plant camas has great potential as a regionally unique, sustainable food crop for the San Juans.



About Camas

Camas, the edible bulb of North American native Camassia leichtlinii and C. quamash, was cultivated and harvested by Native American and First Nations communities up and down the Pacific Coast of North America. This hardy bulb thrives both in the wet coastal meadows of the Pacific Northwest and the rain shadow climates of the San Juan Islands. Careful cultivation that included hoeing, weeding, fertilizing, and periodic burning allowed the Coast Salish communities of the Salish Sea to produce camas in quantities great enough to sustain their communities and to create a surplus to supply regional trade.

Raw camas bulbs are indigestible, and relatively resistant to pests. This is because they store energy in the form of inulin, a oligosaccharide or short chains of simple sugars that cannot be digested by mammals. Eating camas requires that the inulin be broken down into fruit sugar (fructose) through long, slow, moist cooking. Cooked camas is sweet, mildly nutty and rich in fruit sugar.

Proper preparation for easily digestible camas requires 48 hours of moist, slow cooking. Traditionally camas was prepared by pit roasting large quantities from family harvests all at once. A slow cooker works well to bring this sweet, nutty, ancient crop plant into modern kitchens.

This cookbook gives an overview of preparing camas, and provides a sampling of the recipes that were enjoyed at Kwiaht's 2016 First Annual Camas Festival on Lopez Island, WA.

Our development of camas production and preparation techniques was funded by a Specialty Crop Block Grant through the Washington State Department of Agriculture (WSDA).

For more information about Kwiaht's work to bring food camas back as a sustainable food crop in the San Juan Islands visit our website http://www.kwiaht.org

Properly Prepared Camas in a Slow Cooker

Mature camas bulbs may be harvested for cooking at anytime during the growing season, but are easiest to harvest and prepare when they are mostly dormant (July-January). Wild harvesting of camas may not be safe or sustainable, and all of these recipes we're developed for garden grown bulbs. If bulbs are harvested in summer each bulb may need to be split in half to remove the flowering stalk. This can be avoided by removing the flowering stalks at the beginning of the season, which can also encourage the growth of larger bulbs.

Clean bulbs, remove the root end (which may be replanted to form new bulbs) and the top end, and any insect damage or mold, if necessary split bulbs in half and remove the hard central stalk.

To diffuse the heat and avoid overcooking the bulbs on the edge, line the slow cooker well with washed thimbleberry leaves, soaked corn husks, or crumpled parchment paper. Add around a cup of water (depending on the size of your slow cooker—the water should come up to the top of the leaves). Make a large well in the middle and line with two sheets of parchment paper crossed over one anther. Fill this well with cleaned bulbs; a full pot will cook more evenly. Fold the edges of the parchment paper over the bulbs and put on the lid. Set the cooker on low, and allow to cook for 48 hours, adding water as needed (check approximately every 12 hours).

After 24 hours the bulbs will begin to take on an ivory color, and after 48 hours they will be dark brown and very soft. At this point they can be used in any of the following recipes, or frozen, or dried for storage. Fresh cooked bulbs are quite perishable will only keep for a few days in the fridge.

To make camas paste from fresh bulbs, puree in a food processor with enough water to make a very thick paste, use a food mill or sieve to remove any remaining pieces (these pieces may be added to camas ice cream with the paste, but will detract from the smooth texture of camas spread).

To dry camas bulbs for storage, chop fully cooked bulbs, dry in a dehydrator until completely dry, and store in an airtight container. Whole bulbs can be dried as well, but are more challenging to re-hydrate.

Dry camas can also be powdered in a coffee grinder and re-hydrated into camas paste. Grind very fine, and shift, or sieve, to remove remaining larger chunks (which can be added to chopped camas).

To rehydrate dried camas: cover with boiling water (approximately 2 parts water to 1 part dried camas). To make camas paste from powered, dried camas: add 3 parts boiling water to 1 part camas and stir well.

Camas and Sweet Onion Salsa

Spiced only with sweet onion and yellow mustard seed, this mild salsa shows off the nuttiness of camas, and is good alongside salmon or served with fry bread or chips.

½ cup chopped sweet onion
½ cup chopped prepared camas (or re-hydrated dried camas) 1 teaspoon rice vinegar or cider vinegar
1 teaspoon whole yellow mustard seeds
½ teaspoon kosher salt (or ¼ teaspoon table or sea salt) ground black pepper to taste

Mix all ingredients, adjust salt and vinegar to taste. Camas salsa will keep for a week in the fridge.

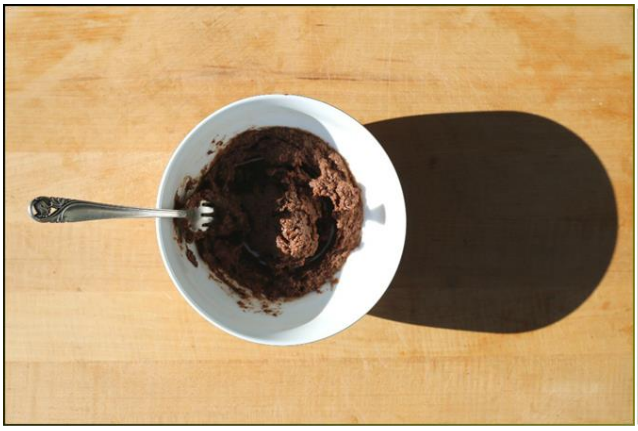

Sweet Camas Spread

A mildly sweet spread, reminiscent of chestnut jam. The chocolate version is lighter and less sweet than chocolate nut spreads like Nutella:

¼ cup camas paste (or camas paste made from dried, powdered camas) 1 tablespoon water
1 tablespoon sunflower oil

(Chocolate Camas Spread variation—add 1 tablespoon Dutched cocoa)

Re-hydrate dried, powered camas if needed. Stir water and oil into camas paste until very smooth. Add more water if the texture is too stiff. For chocolate version stir in cocoa. Sweet Camas Spread is very perishable, and only keeps for a few days in the fridge, chilled camas spread may need to be thinned with a little more water. Serve on crackers or toast, or with cheese.




Camas Albondigas (meatballs)

The mild nutty, sweetness of camas pairs very well with beef, and this recipe can also be used to make camas hamburgers (which may be served with camas salsa). Recipe makes enough for 2 burgers or around 20 small meatballs.

1/2 lb ground beef (80/20 or lean, not extra lean)

1/2 cups chopped prepared camas (or re-hydrated dried camas) salt to taste (optional)

Re-hydrate camas if necessary. Mix beef and chopped camas, roll into marble sized meatballs and cook covered in a hot pan over medium-high heat, shake the pan frequently to keep the albondigas from sticking. Serve warm.

Camas Ice Cream

Creamy and gently sweet, ice cream shows off the subtle flavor of cooked camas. Camas and honey provide all of the sweetness in this recipe. Camas ice cream can be prepared over 2 days, making and chilling the custard the first day, and churning and freezing it on the day you plan to serve. Ice cream can also be made ahead and kept frozen, but with no stabilizers, it should not be allowed to thaw and refreeze.

2 cups whole milk (divided) 2 cups cream
½ cup honey
1 cup camas paste (or re-hydrated paste from dried, powered camas) 6 egg yolks

Re-hydrate dried, powdered camas if necessary. Mix camas paste and 1 cup milk in a pot until very smooth, bring to a simmer over medium low heat, stirring frequently, and cook for 10 minutes. It will thicken. Add the remaining cup milk, cream, and honey and heat, stirring frequently, until steaming. Meanwhile lightly beat egg yolks.

Slowly stir 1 cup of hot mix into the egg yolks to temper. Add the yolk mix to the pan and heat, stirring frequently, until very hot but not boiling, at this point the custard may thicken more. Remove from heat and let cool. Freeze 1 cup of custard, chill the remaining custard in the fridge overnight, or until quite cold. Add frozen custard to chilled custard and stir until the frozen dissolves.

Freeze in an ice cream maker according to the manufacturer's instructions.

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Project Title: Evaluating New Asparagus Varieties for Disease Resistance

Partner Organization: Washington Asparagus Commission

PROJECT SUMMARY

The asparagus industry is rapidly changing its production methods by switching to new varieties and more intensive planting methods. Some new varieties are known to be more susceptible to diseases in other asparagus growing regions. More intensive production practices include planting crowns at higher densities which can create conditions favorable to foliar fungal pathogens and increase stress on crowns which can favor soil pathogens. This project proposes to evaluate for the first time the over 150 varieties currently in a variety trial for the asparagus industry and to do disease evaluations in the first plantings of the newly commercial varieties of asparagus, several of which are of varieties more susceptible to disease.

Growers are concerned that the varieties they have planted which have much higher yields than traditional varieties are more susceptible to diseases. Before more acres are planted they want some assurances that diseases will not become more of a problem due to varietal selections. Additional objectives is to ascertain where a new disease, Phytophthora crown, root and spear rot, has reached Washington and to increase grower awareness on asparagus diseases.

This project did not build on a previously funded SCBG.

PROJECT APPROACH

The project was initiated by surveying the asparagus growers about their interest, concerns and vulnerabilities to asparagus disease at the annual grower meeting. Over the next two years the Washington Asparagus Commission research plots and grower fields that represented a large percentage of the new varieties planted in Washington were surveyed. Initially the project began with vegetable pathologists from Michigan State University. They did not fulfill their agreement on how often they would visit and sample fields. As a result a contract with WSU vegetable pathologist (Dr. Dennis Johnson) was established. During the course of the field work one asparagus spear (out of thousands and thousands) was thought to have phytophthora and WSU vegetable pathologist was unable to confirm it had the disease. Fusarium and asparagus rust was not an issue in the fields or the plots. Perhaps one of the most interesting outcomes of this project is that it became apparent that growers were misdiagnosing Stemphyllium (purple spot) for asparagus rust. This was a significant issue. Dr. Johnson spoke at the annual meeting and field days and he provided grower education on proper diagnosis and treatment for both diseases. Additionally Dr. Johnson created an asparagus disease website for growers to use and obtain additional information on the diseases. The disease management guidelines are on Dr. Johnson's website at: http://plantpath.wsu.edu/dajohn/asparagus/.

University plant pathologists provided technical assistance, training and survey support to the industry. The Commission funded additional survey and monitoring. Both Commission funded personnel and University plant pathologist provided training to the industry. The industry seemed appreciative, especially growers who had been applying the wrong fungicides because they had misidentified an asparagus disease.

All but one of the diseases involved are specific to asparagus. This project was very specific to asparagus.

GOALS AND OUTCOMES ACHIEVED

Project Activity	Measureable Outcomes
Conduct Survey at Annual WAC Meeting	Growers representing over 75% of production were surveyed
Develop disease management guidelines	Johnson and Schreiber did this
Asparagus variety trial will be surveyed every 2 weeks in 2014	The set of asparagus trials were surveyed every two weeks during the appropriate seasons (harvest, post-harvest)
Commercial asparagus fields will be surveyed every 2 weeks in 2014	Johnson/WSU did this, and when he could not, Schreiber's staff did this
Asparagus variety trial will be surveyed every 2 weeks in 2015	Johnson/WSU did this once a month and when he could not Schreiber's staff did this
Analyze Data in 2015	Johnson/ WSU did this
Commercial asparagus fields will be surveyed every 2 weeks in 2015	Johnson/WSU did this once a month and when he could not, Schreiber's staff did this
Prior to WAC Annual Meeting develop disease management and educational materials	Johnson/WSU did this. The results of this were provided to growers and placed on the asparagus disease website

Prior to season start (April) 2015 growers representing 75% of Washington asparagus production trained on disease management	Johnson/WSU this was done at the annual meeting and at the grower field day. Growers representing more than 75% of production were trained
Develop Disease Management Guidelines	Schreiber/ADG, Johnson WSU was done

There were no plans for long term outcomes.

The planned goals were all accomplished. The one challenge was the lack/poor cooperation with the MSU scientists. When the WSU scientist became involved all tasks were accomplished and the work ended up costing less than planned.

The biggest finding was not finding asparagus crown, stem and spear rot in the state (Washington is the only major asparagus production region in the U.S. that does not have it. Purple spot, Fusarium and asparagus rust did not show up in either the variety trial or the commercial fields that were surveyed at levels that were any different from the more traditional varieties. At this point there has not been an increase in disease pressure that has been seen in other growing regions (Michigan, Ontario) that are growing the new varieties that Washington is growing.

Growers representing more than 75% of production were trained on disease identification, biology and management.

BENEFICIARIES

The primary group who have benefited from this are Washington asparagus growers. A secondary group who have benefited from this are the handlers who purchase asparagus from Washington growers.

This is difficult to state. One of the objectives of this project was to determine if the new asparagus varieties were more likely to have disease than the traditional varieties. A project conclusion was that at this point in time is that the new varieties do not have more disease. It is unclear how to quantify the economic value of this. It is estimated that one in five applications of fungicides were misapplied due to inaccurate diagnosis of disease. It is quite likely that as many as a thousand acres of fungicides may have been applied for the wrong disease.

LESSONS LEARNED

The MSU plant pathologist were good to work with but it was simply too far for them to come here on a monthly basis to work on this project. Initially WSU scientists were unavailable and unable to commit to this project. If the project were to done again, it wouldn't be started without having more locally available scientists to work with. One has to be flexible in measuring outcomes. At one point the objective had been hoped to reach 75% of growers but ended up working with growers that represented 75% of production. This is a lower number of growers, but likely to represent a higher percentage of production.

It was expected that it would be found that the newer varieties of asparagus had more disease issues due to their higher level of susceptibility than traditional varieties. It was unexpected to find that disease pressure was no different across all varieties. It is thought that since 2014 and 2015 were warmer years perhaps conditions were not conducive to disease development, or simply they are not more susceptible to disease in local growing conditions.

The industries goals were achieved. The industry seems happy with the project, particularly since it was determined that planting the newer varieties has not resulted in higher disease pressure.

ADDITIONAL INFORMATION

The Washington Asparagus Commission contributed $8,000 in 2014 and $10,000 in 2015 and the WAC sought and received $10,000 and $20,000 from the Washington State Commission on Pesticide Registration to support this project (all in cash). The asparagus growers provided fields to survey and the variety trials were financially supported by the WAC. It is hard to place an in-kind value on this but will call it $10,000 in 2014 and in 2015.

CONTACT INFORMATION

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Project Title: Implementing Water Supply Strategies

Partner Organization: Whatcom Farm Friends

PROJECT SUMMARY

Specialty crop growers in Whatcom County have been actively working on addressing the disconnect between water use for irrigation and the state water code for over 20 years. In 1993 farmers became aware of the potential problems this might cause when the local tribes determined to quantify their in-stream water right on the Nooksack River. Growers formed an organization to address this challenge and through a survey it was determined that up to ¾ of Whatcom irrigation water use was either unpermitted or not adequately permitted. The grower group, Whatcom Farm Friends, worked through the legislative process, as the agriculture representative in the watershed planning process, and in direct negotiations with the other major water users in the area to find creative solutions to a problem that challenges the very existence of crop production in Whatcom County.

There are over 450 Whatcom County specialty crop farmers who require secure access for irrigation water. The first two elements of the Whatcom Farm Friends water strategy that are funded in this project were completed within the timeline of the project and provided specialty crop growers with a solid organizational foundation for addressing water issues and outline the partnerships with other non-ag water users.

This project was not built on a previously funded SCBGP project.

PROJECT APPROACH

Farm Friends provided the administrative support for the committee that explored organizational options and led the creation of 4 new Irrigation Districts (called Watershed Improvement Districts) which followed the leadership of the two existing Districts in Bertrand and North Lynden. Farm Friends helped raise $157,000 from farmers and ag-businesses and $35,000 from a partnership grant via the Whatcom Conservation District. These funds were used to organize the farmers to prepare the petitions to form the 4 new WIDs, post the bonds to conduct the elections under the direction of Whatcom County, and provide the legal help to get the WIDs formed and organized according to State statutes.

Farm Friends then shepherded the collaboration of the six Whatcom County Watershed Improvement Districts (WIDs) into the Ag Water Board (AWB). The AWB was established by an Interlocal Agreement of five of the six WIDs in early 2015 and the sixth WID has agreed to join in 2016. Specialty Crop producers led this effort as access to irrigation water is a crucial issue for specialty crop farmers.

The Out-of-stream water users group was transformed into a reincarnation of the WRIA #1 Watershed Planning Unit. Farm Friends, which transitioned into Whatcom Family Farmers, provided the designated ag representation to this body throughout 2014-16. Farm Friends has also worked with the Public Utility District and the cities of Lynden and Bellingham to organize a Whatcom Water User's Group consisting of the AWB, city water managers, the PUD, water associations, and Whatcom County which has been meeting since fall, 2015.

Farm Friends was assisted by the Whatcom Conservation District with multiple maps and parcel databases. The Whatcom PUD provided advice and support with the organization of the Out-of-Stream Water Users group. Whatcom County cooperated with proving the facilitation services for the Watershed Planning Unit.

The project has multiple funders. SCBG funds provided less than 30% of the project budget. Specialty Crop farmers made up 60% of the leadership team directing the project.

GOALS AND OUTCOMES ACHIEVED

Goal #1 Ag water use and needs fully integrated into the County water use plan

Goal #1 will always be ongoing. The project has had strong ag investment in large part due to the SCBG funding. Agriculture is clearly represented in all water related policy discussions occurring throughout Whatcom County. This is evidenced in that the Ag Water Board fill the ag seat in the Watershed Planning Unit and on the Water Users Group.

Goal #2 Decision on an Ag Water District

Goal #2 was accomplished with the creation of 4 new WIDs in 2014 and the organization of the Ag Water Board in 2015. Development of the Scope of Work and budgets of the AWB in 2016 and beyond are current projects. There are also discussions around water settlement negotiations initiated by Lummi Nation which would be strongly supported by the AWB provided the details of how these settlement negotiations are developed.

In water policy all goals are long-term! The purpose of Whatcom Family Farmers and the Ag Water Board is to ensure that farmers have the ability to access legal water to irrigate their crops and to do so in a manner that respects the in-stream flow needs of fish and Native American neighbors. The structure to both discuss these difficult issues is much improved because of the Water Strategies implemented in this project. The ability to actually implement projects on a watershed scale is also much improved with the ability to use the assessments and powers of the WIDs to actually implement water agreements.

#1 Ag water use and needs fully integrated into the County water use plan
Goal: Consistent ag participation in the County Water User's Group
Target: Farmers believe that water use information and plans to provide long term water certainty are accurate and incorporated into water plans.
Benchmark: TBD
Performance measure: % of meetings attended, farmers water interests recognized.
Farm Friends provided agriculture representation to the Planning Unit's monthly meetings throughout 2015-16. The development of a separate Water User's Group was initiated by Farm Friends in partnership with the Whatcom PUD and is actively functioning.

#2 Decisions on an Ag Water District
Goal: Creation of an Ag Water District to sustain long-term ag participation in water management
Target: Documented process to identify best means to organize specialty crop water users, amount of contacts with growers to prepare proposal, final decision on what type of district to create, where the district is located, who will govern the district, and what powers are provided for the district to use to implement water strategies that address grower needs.
Benchmark: no existing countywide district representing ag water interests.
Performance measure: Decision by farmers whether to establish a district or not.
The Ag Water Board was organized by the member WIDs in early 2015. It established an aggressive 2015 and 2016 work plan and budget and now serves as the indisputable and accountable voice of farmers on water issues. Farm Friends, now Family Farmers, provided all the administrative effort for this organization and provides water quantity and quality services through a contract with the AWB.

All activities accomplished within the timelines.

Project Activity	Responsible Party	Timeline (*month and year*)
Identify AG representative to out-of-stream water users group	WFF Board and staff	October 2013
Identify organizing options for Ag Water District	WFF staff and contractors	October 2013
Select preferred option for organizing	WFF Board	November 2013
Farmer and farm group meetings to discuss Ag Water District	WFF Board and staff	Nov 2013 – Sept 2014
Referendum of growers on Ag Water District	WFF, County	November 2014
Assist initial functions of Ag Water District	WFF staff and contractors	Dec 2014 – Dec 2015
Support Ag Water representative to County out-of-stream water users group – serve as the portal for information for growers and water management modelers and planners	WFF staff and contractors	Nov 2013 – July 2016
Maintain grower communication through website, newsletters, presentations at grower meetings, WFF board meetings.	WFF Board, staff, and contractors	Oct 2013 – July 2016

BENEFICIARIES

Beneficiaries of this project are specialty crop farmers, all Whatcom farmers, community partners, Tribal community, and natural environment.

There is no question over who speaks with authority for agriculture on water issues. This project allowed for the ability to make and enforce commitments on behalf of farmers.

LESSONS LEARNED

A lesson that was reinforced is how difficult it is to get many famers working together and how valuable it is when it is achieved! Whatcom farmers had no clear history of working together across commodity groups. There were efforts by non-profits like Farm Friends but with voluntary membership it was difficult to get more than 30% of farmers involved and because of that the impact of the Farm Friends voice was always suspect. Implementing the Water Strategic Plan has left us in a much better place!

Plans proceeded according to expectations. The time it takes to get organizing activities together is always longer than expected.

All goals were met. WSU is in a good position to engage with the rest of the community in water settlement negotiations proposed by Lummi Nation.

ADDITIONAL INFORMATION

COST CATEGORY	Grant Funds	Amended	Invoiced	Balance	Total Project Cost
Salaries	$44,138	$29,925	$29,925	$0	$29,925
Benefits	$6,621	$4,489	$4,489	$0	$4,489
Travel	$3,132	$521	$521	$0	$521
Supplies	$3,795	$3,450	$3,450	$0	$3,450
Contractual	$16,500	$33,595	$33,173	$422	$33,595
Other	$814	$3,020	$3,442	-$422	$3,020
Matching Time	staff hours	720 @ $40/hr.	$28,800	-	$28,800
Matching Time	farmer hours	4,843 @ $25/hr.	$121,075	-	$121,075
Matching Funds	farmer and ag business contributions		$157,000	-	$157,000
TOTAL	**$75,000**	**$75,000**	**$75,000**	**$0**	**$381,875**

Additional project information can be found at:
ADC Flyer
Lynden Tribune article
Bill Clarke - new solution to old problem _ Lynden Tribune.pdf
Structure Diagram
Map of WIDs
www.agwaterboard.com
Includes:

- Story Board
- Each WID website link
- Recent newsletters

CONTACT INFORMATION

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Project Title: Access to Sustainability Resources

Partner Organization: Northwest Food Processors Association (NWFPA)

PROJECT SUMMARY

Through a survey of food processors in 2012, NWFPA determined that while leadership in most companies was committed to sustainability, most companies, and especially the smaller companies, struggled to know where or how to begin their sustainability planning and efforts. Information, training and resources were identified as high priority needs. The purpose of the project was to develop, promote and disseminate sustainability information, training and resources for food processors.

Over the past five years, there has been a dramatic "changing national (as well as global) landscape" that is impacting food processing operations, their costs of production, and potentially their competitiveness. Elements of this change include: Energy price increases/volatility; greenhouse gas emissions and carbon regulation (taxes/market approaches); water availability and cost concerns; more stringent environmental laws and regulations; climate change impacts; and customer demands for "green and sustainable" products. The project was designed to provide information and resources to food processors to help them address and mitigate the impacts presented by the above elements.

This project builds on work funded under an Oregon-Idaho Bi-State Food Processors Specialty Crop Sustainability Initiative (2010-2012), which developed resources for the food industry. Resources produced with those funds were evaluated, revised, further developed and expanded and converted to forms that are easily accessible and useable by food processors. For example, the Sustainability Guide was revised and redeveloped into a step-by-step, on-line tool to assist food processors in creating a sustainability plan. The Industrial Water Training was beta-tested on-site at a food processing facility and then revised and converted into a complete package of instructions and resources that food processors can use on-site to train their employees in water conservation and efficiency. The Sustainability Micro Case Studies publication was updated and revised and the number of case studies increased by over 50%.

PROJECT APPROACH

Establish Industry Advisory Groups to gain input on training and resource development; meetings

NWFPA's Sustainability Committee was established as a key advisory group for the project. About 83% of the members are specialty crop and of these, 90% have plants in Washington. The Committee provided extremely valuable advice and recommendations on project deliverables as well as review and evaluation of training and resource products. The NWFPA Energy and Environmental Committees provided input and review as well.

Two additional regional advisory groups were established, one in Bellingham, Washington and one in Quincy, Washington. A sustainability workshop was held in both of these locations. Twenty specialty crop food processors attended the Bellingham workshop and twenty-five attended the Quincy workshop. The purpose of the workshops was to educate attendees on sustainability, distribute resources, and to facilitate discussions with attendees on their companies' needs and challenges and on training and resource needs.

Feedback from attendees on the workshops was very positive. They particularly appreciated that the workshops were local as such training is not often available near rural areas. NWFPA collected and analyzed the input from the workshops and determined the priority needs and challenges. Top challenges were: environmental regulations; identifying opportunities at plants and resources to provide solutions; metrics, data interpretation and management; and water use and efficiency and wastewater.

Develop Industrial Water Use Training – Train-the Trainer

NWFPA beta-tested at a specialty crop food processing facility the Industrial Water Use Training that was developed for NWFPA under the Oregon-Idaho Bi-State Food Processors Specialty Crop Sustainability Initiative. Based on feedback from the test site, the training was considerably modified and expanded. The "Water Sustainability Training Course" now consists of a group of materials, which can be used by facility team leaders or consultant trainers to deliver the Course on-site to facility employees. The Course includes an instruction document for the trainer that includes questions to assist the trainer in compiling information specific to the facility and in customizing the training materials to the facility. A facility water balance exercise is part of the Course and a workbook and video instructions for the trainer were developed. The employee training consists of three Power Point presentations (modules) designed to educate and engage facility line, line supervisory, maintenance, engineering and management staff on the importance of water sustainability and the activities routinely performed to achieve efficient and cost-effective use of this natural resource. Each module was developed to first educate and then build off the prior module. Another document provides examples of water conservation and efficiency actions that employees could adapt or modify for use in their facility. These examples came from the latest edition of the Sustainability Micro Case Studies for the Food Industry.

The *Water Sustainability Training Course Materials* are available at no cost for download on NWFPA's website at www.nwfpa.org/water.

Develop E3 Training "Taster" and Conduct Assessments

NWFPA's partner, Impact Washington, developed a presentation that gives an overview of the federal multi-agency program E3 – Economy, Energy, and Environment. It describes who can benefit from E3 and the benefits that can result for food processors. The presentation also includes a brief summary of savings achieved at one food company as well as the savings opportunities, including potential financial savings, at the two specialty crop companies that received assessments under the project. The E3 "Taster", E3 Assessments for Food Processors: Energy, Environment, Economy, is available for download on NWFPA's website at www.nwfpa.org/planning-resources.

E3 Assessments were conducted at two specialty crop food processors in Washington State. One was at a bakery, Bake Works, in Vancouver, Washington that produces fruit bars using Northwest specialty crop fruit, which are distributed to many school districts around the country. The second site was Tieton Cider Works in Yakima, Washington, which produces many varieties of fruit ciders that it distributes nationally.

Impact Washington was responsible for the Energy Assessments (conducted by Tim Burrows of Northmore) and Lean Productivity Assessments (conducted by Bill Paugh, River States, Inc.). Impact Washington concluded that "Even though the companies that underwent the assessments are small, the project educated these companies on their opportunities and showed them that even small productivity gains and energy changes can add up to significant dollars and time savings, and can prevent future capital expenditures that can be avoided with better stewardship of resources. It also showed that the E3 approach pays off on companies' bottom lines as well as creating energy, water, and environmental benefits that go to the Triple Bottom Line."

The Energy Assessments provided: an energy baseline; analyzed energy consumption; reviewed energy tariffs; provided high level energy breakdown; described relevant installed equipment; and identified potential opportunities to reduce energy cost. Cold storage was found to be a highest energy use and key area of potential opportunities for savings. Summaries of the results and recommendations from the Energy Assessments, E3 Energy Assessments for Food Companies, are available on NWFPA's website at www.nwfpa.org/sustainability-energy.
NWFPA's consultant, John Thornton of CleanFuture, conducted the two Water Assessments. The Water Assessments provided: a water baseline; analyzed water consumption; analyzed water bills; developed a water balance/water flow diagram; described current water use; and identified potential opportunities for water and cost savings. The most significant water cost savings identified is on the wastewater side—managing discharges to avoid BOD loading and charges. Due to different layouts and equipment configurations within facilities, water monitoring is not straightforward and often must be customized. Based on the needs observed by Mr. Thornton at the assessment sites, he prepared a guide on *Water Assessments and Lessons Learned* that will assist food processors in measuring and monitoring their water use. This guide and information from the water assessments will be available on NWFPA's web site at the Water tab.

Online Sustainability Guide

The Sustainability Guide that was created under the Oregon-Idaho Bi-State Food Processors Specialty Crop Sustainability Initiative was redeveloped and repurposed into a step-by-step approach that food processors can use to develop their sustainability plans. The Guide provides case examples for the three areas of sustainability, examples of vision statements, and examples of objectives, goals and metrics. A recommended time-line for planning is included and fillable and printable forms are provided for companies to record sustainability opportunities, vision statements, and objectives, goals, and metrics for use in planning. The *Guide to Sustainability Planning* is available on NWFPA's website at www.nwfpa.org/planning-resources.

Update the Sustainability Micro Case Studies

Under the project, NWFPA prepared and published a second edition of the *Sustainability Micro Case Studies for Food Processors: Working to Make a Better Tomorrow*. The new title is *Sustainability Micro Case Studies for the Food Industry: Working to Make a Better Tomorrow*. This slight change (from "processors" to "industry") reflects that case studies from suppliers and customers of food processors are included as well as food processor case studies. These other organizations are part of the food industry and sustainable practices throughout the supply chain contribute to the sustainability of the overall industry. The second edition contains the original case studies, many of which have been updated to reflect changes and/or more recent results since the first edition. Further 28 new case studies were added (a 55% increase over the first edition).

Sustainability Micro Case Studies is available at www.Amazon.com. It is also can be accessed through a link on NWFPA's web site at www.nwfpa.org/priorities/sustainability.

Purchase Portable Ultrasonic Equipment for Industrial Water Use Monitoring

NWFPA purchased a Sierra Portable Ultrasonic Flow Meter (Model 210i) that was used in the Water Assessments. This flow meter is now available on loan for food processors to use in assessing and monitoring their water use. John Thornton has prepared a use guide to accompany the meter based on his experiences using it in the Water Assessments.

Gather Information on Metrics used for Measuring Success of Sustainability Practices

NWFPA conducted a survey of its food processor members to determine what metrics are used to measure progress toward sustainability goals, whether they use software to manage and track sustainability work, and whether they communicate or publish the results of their efforts. The results of the survey, *NWFPA Membership Sustainability Survey*, are available on NWFPA's website at www.nwfpa.org/planning-resources. The survey revealed that most companies are measuring and tracking key environmental sustainability efforts: electricity and natural gas consumption; freshwater consumption; wastewater discharge and waste to landfill. Social and economic sustainability efforts are not as widely measured and tracked. Many companies do not use software to manage and track progress, but those that do track, use Excel.

Compile Metrics into a Resource and Disseminate for Use

NWFPA created a "Metrics" tab on the Sustainability page of its website at www.nwfpa.org/priorities/sustainability. The Metrics page includes a discussion and examples of the relationship of metrics to sustainability plan objectives and goals. It also includes three Power Point presentations from NWFPA's 2014 Sustainability Summit on practical application of planning, use of metrics and tracking progress. In addition, there are links to two key metrics resources. NWFPA used the metric topics identified in the survey of the membership described above and developed a table that shows examples of metric units and metric ratios for each of the topics. This table, NWFPA Member Metrics, is available at www.nwfpa.org/metrics.

NWFPA's project partner was Impact Washington, a non-profit organization specializing in manufacturing consulting services for Washington manufacturers. Impact Washington is part of the NIST Manufacturing Extension Partnership (MEP) network. Impact Washington prepared the E3 "Taster" presentation and managed the Energy and Lean Productivity Assessments.

The companies that received the E3 Assessments – energy, water, and lean productivity were specialty crop processors. While NWFPA has posted the project publications and resources to the web site, specialty crop processors have received personal notifications of the availability of these resources. Specialty crop processors made up the attendees at the Sustainability Workshops in Bellingham and Quincy and received hard copies of the Sustainability Micro Case Studies for Food Processors and the Sustainability Guide. They also personally met with their electric and natural gas utilities at these workshops to discuss efficiency programs and incentive opportunities for their facilities and had individual conversations with NWFPA staff regarding resources and sustainability questions.

GOALS AND OUTCOMES ACHIEVED

Outcome 1: Increase knowledge and ability to create plans and achieve efficiencies.
NWFPA tracked registrations and participation rosters and set up a tracking system on the NWFPA website whereby the documents downloaded and the identity of persons downloading the documents could be compiled.

Outcome 2: Pilot development of metrics.
NWFPA conducted a survey that focused on metrics. Two energy assessments and two water assessments were conducted.

Both expected measurable outcomes 1 and 2 should be considered long term as gathering of this information and implementation is complex and subject to delays and other factors. See discussion under the Lessons Learned section of this report.

- **Establish Industry Advisory Groups and hold meetings**. NWFPA's Sustainability Committee and Environmental Committees served as advisory groups as well as a processor advisory groups in Quincy and Bellingham, Washington. These groups provided valuable input on resources and training.
- **Develop "Train-the-Trainer" Industrial Water Sustainability Training**. A complete package of training materials was developed and is available for download on NWFPA's website.

- **Develop "Taster" materials for E3 training and deliver assessments**. Impact Washington developed the "Taster" materials, which are available on NWFPA's website. Two E3 assessments and two water assessments were conducted.
- **Develop Online Sustainability Guide**. The Guide to Sustainability Planning was developed and is available for download on NWFPA's web site.
- **Update and Disseminate Sustainability Micro Case Studies**. The original Sustainability Micro Case Studies has been updated, expanded, revised and published. It is available for purchase on Amazon. NWFPA ordered copies which will be disseminated at NWFPA's Expo and Sustainability Summit. Thousands of copies of the original Sustainability Micro Case Studies have been disseminated over the course of the project.
- **Purchase portable ultrasonic equipment for water use monitoring**. This equipment was purchased and used in the water assessments. It will be available for loan to food processors.
- **Gather information on Metrics used to Measure Success of Sustainability Practices**. A survey was conducted that provided considerable information on these metrics.
- **Compile Metrics into a Resource and Disseminate for Use**. Metrics from the survey were compiled into a document. A Metrics tab was created on the NWFPA web site's Sustainability page that includes this document as well as other metrics resources.
- **Goal to increase knowledge and ability of specialty crop processors to create sustainability plans**. Through the Sustainability Workshops, NWFPA has directly increased knowledge and ability. The resources and tools that were developed under the project will significantly contribute knowledge and increase their ability to create these plans.
- **Goal to pilot development of metrics**. The survey results, metrics resources and Sustainability Planning Guide will help processors understand the importance of metrics to their sustainability plans. While NWFPA did not establish baselines for facilities other than those that underwent the assessments, issues have been identified and a path forward to achieve this has been determined.

Outcome 1:
Target: The project targeted 250 processor personnel in at least 30 Washington specialty crop facilities accessing sustainability resources. While NWFPA exceeded the facility target, the personnel target was not achieved. NWFPA recorded 84 processor personnel in 45 Washington specialty crop facilities.
Benchmark: Based on a survey conducted prior to the start of the project, 2/3 of specialty crop processors were estimated to have no sustainability plan, budget or training. The survey conducted as part of the project indicates that about 60% of the responding sample are actively engaged in sustainability. This sample was largely composed of the bigger specialty crop processors. These facilities are more likely to have sustainability programs and budgets, so this may be skewing the results.

Outcome 2:
Target: Electricity, natural gas and water baselines were established for the facilities that underwent the E3 assessments. NWFPA was not able to gather baselines from other participants.
Benchmark: NWFPA was not able to establish baselines for other participants. See the Lessons Learned section of the report for further details.

BENEFICIARIES

Two specialty crop processors in Washington benefitted from E3 assessments at their facilities. Other specialty crop food processors in Washington benefitted from the local workshops that NWFPA conducted as well as the consultations with their electricity and natural gas utilities at those workshops. Several processors made appointments for on-site visits with their utilities.

Specialty crop food processors and the food processing industry in the Northwest and the nation have benefitted from the publications and tools completed under the project, all of which are available for download or accessible on NWFPA's web site. NWFPA's Member Survey, the Sustainability Workshops, and NWFPA's Advisory Groups have all indicated that these publications and tools are the resources that food processors need to jump start or advance their sustainability efforts.

The two food processors that underwent the E3 Assessments each received about $12,000 in consulting services. One company received recommendations for productivity efficiency opportunities estimated at $110,600 as well as extensive recommendations for future energy savings (cost savings not estimated). The other company received recommendations for productivity efficiency opportunities estimated at $65,500 as well as recommendations for future energy savings (cost savings not estimated).

LESSONS LEARNED

Through the Sustainability Workshops in Bellingham and Quincy, NWFPA learned that bringing resources and personnel to training that is held locally is very important to rural food processors. It also provides an opportunity to reach companies and personnel that typically do not travel to Seattle or Portland for training.

Closely monitor the progress of partners and consultants toward completion of activities and take immediate action to correct if delay occurs as other dependent activities may be delayed as well.

Find a way to assure that medium-sized and smaller specialty crop processors are included in surveys so that the larger companies, which usually participate, are not skewing the results.

NWFPA was not able to conduct a water assessment at the first facility selected for the assessment because nearly all of the pipes were insulated and many of its water pipes were behind walls. The insulation would need to be cut and walls would have needed to be removed in order to attach the portable monitoring device. NWFPA should have conducted an on-site visit before it started the assessment to assure that the necessary monitoring was feasible. This required NWFPA to engage another site for one of its two water assessments.

The quality and relevance of the input provided by the specialty crop processors at the Sustainability Workshops was an unexpected result. NWFPA's Sustainability Committee is using the input from these workshops to inform NWFPA's sustainability program development and future resources and training. NWFPA was able to combine the input from the workshops with concurrent work by NWFPA's Technology Steering Committee. As a result, NWFPA was able to create a list of the priority needs, challenges and solutions for food processors. Few industry sectors have produced such a list. NWFPA has shared this list with the Idaho university system and Washington State University, which are using this input to guide research and development and educational curricula to benefit food processing. In collaboration with the Idaho university system, NWFPA and food processors in Washington, Oregon and Idaho will be piloting a new innovative wastewater treatment methodology, which addresses one of the top challenges identified in the Sustainability Workshops.

A second unexpected result is that the resources and tools developed under this project are the same resources and tools that the specialty crop processors told NWFPA they needed at the Sustainability Workshops. It is also interesting that they address their identified top challenges and needs.

A third unexpected outcome was that NWFPA's Sustainability Committee found the Member Sustainability Survey to be highly informative. They have asked that NWFPA expand the pool of respondents (especially to include more medium-sized and smaller facilities) and conduct an annual survey that will be used to track food processing industry progress in sustainability.

Outcome 1: NWFPA did not achieve its personnel target of 250. In retrospect, perhaps the personnel target was unrealistic, or unrealistic given the time-frame. Nevertheless, a different approach to contacting and engaging personnel at specialty crop facilities is required. NWFPA typically uses email to contact personnel. While 45 facilities accessed NWFPA resources, only 84 different individuals were involved. About half of these individuals consistently participated and accessed resources, and incidentally were from the large processing facilities that are consistently taking action to become more sustainable. The challenge going forward is how to significantly expand the numbers and sources of individuals accessing resources.

Outcome 2: NWFPA has determined that few food processors, except the large companies, are monitoring and tracking water use, wastewater discharge, waste and carbon emissions. Therefore, it is not possible to establish baselines for these companies. NWFPA's Sustainability Committee has recommended that NWFPA advance this tracking and monitoring in food processing facilities by setting an industry water intensity (water used per unit of production) reduction goal like the 25% in 10 years energy intensity reduction goal that was set in 2009. NWFPA would assist facilities, through use of this project's Water Sustainability Training tools and the portable water monitoring equipment, in establishing water baselines and tracking progress to the goal. A water intensity goal would also heighten awareness of water use and promote conservation and efficiency solutions. This approach works. Prior to 2009, many of NWFPA's members did not have energy baselines, but now most facilities do and they are making progress toward reducing their energy intensity. The Sustainability Committee has also requested that NWFPA educate and provide food processors access to carbon emissions calculation tools so they can establish carbon baselines and track progress on carbon reduction.

ADDITIONAL INFORMATION

NWFPA Cash Match -- $53,681.63 total

Item	Amount
Indirect Administration (29.1% federal approved rate)	$46,140.01
Travel to Sustainability Workshops	$327.63
Supplies	$2,530.26
Production costs for Sustainability Workshops and Sustainability Micro Case Studies	$3,637.30
Sustainability Workshop Expenses (catering, printing, AV)	$1,046.43

In-Kind Match -- $50,873.81 total

Source	Amount	Use
Bake Works, Inc.	$8,300	Plant personnel work on the E3 assessments.
Bake Works, Inc.	$600	Supplies for the E3 assessments.
John Thornton/Clean Future	$30,798.81	Charged the project a much reduced rate, the difference was contributed as in-kind match. This funded work on the following: water assessments, Micro Case Studies, Water Training materials and beta testing of the training, investigation of portable water monitoring equipment and training at the Quincy Sustainability Workshop.
Food Industry Personnel	$10,650	Participation of industry personnel in advisory group meetings and workshops.

To accommodate the tools and resources developed under the project and as a means to disseminate the tools and resources, NWFPA totally revised the Sustainability pages on its web site. NWFPA will continue to develop out its Sustainability pages and add tools and resources.

CONTACT INFORMATION

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END OF REPORT